Photography in Clinical Medicine

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Editor

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To my father

Foreword 1

Since the beginning of photography in the 1830s, this newly invented technique has been instantly used in all areas of medicine and science for documentation purposes.

And if we look at the development, today we cannot live without photographic pictures. From the once analogous daguerreotype to today's digital age, the medium has undergone various interesting intermediate stages.

It will not take much longer that the last human is able to take a picture of his world environment at any time and send it immediately to the other end of the world.

The dermatologist Paola Pasquali recognized early the importance of photography for medicine and especially for dermatology.

Early on in this medical discipline, illustrations and photographs were used for student instruction and documentation.

In her publication *Photography in Clinical Medicine*, she not only describes the technical, historical process from a very personal point of view but also deals with the general language of photography.

How true is a photograph? Can photography also lie? Is a photo always a document? What else could we never see without photography?

What influence does photography have on social contexts?

Photography lets us share the lives of others and lets us see what we would normally never see.

Psychiatry, war and death, and also the forensic side of the police with its "mugshots" are the subject of consideration by Paola Pasquali.

The interesting field of Alphonse Bertillon's anthropometric system for the first person identification allows her to think about the portrait in science.

She quotes Roland Barthes and describes her view on various photo books. Women in medical photography as well as a look at the undefined limits between science and art ultimately let them end up into the many international archives whose resources are immensely important to scientists. She also asks if we have the right to publish pictures that show people only as freaks.

The many selected and sometimes rare pictures show a very personal view on the field of medical photography. Their focus does not claim to be complete or systematic.

You can feel that Paola Pasquali has fun and interest in dealing with this large and seemingly confusing medium of medical photography.

2019

Wilfred H. G. Neuse, DGPH
Photograph and Multimedia-Artist

Foreword 2

Since its invention, photography has played a critical role in the practice of medicine, especially for visual specialties such as dermatology. It serves as a means of precise documentation of disease or procedures as well as a method of communication and a vital educational tool. The detailed information contained within *Photography in Clinical Medicine* successfully counters the lament that health care professionals no longer possess the necessary skills required for high-quality medical photography. In addition to providing a firm foundation in basic principles of photography and attendant key equipment, there is a series of specific chapters that contain both theoretical and practical insights into a wide range of topics from 3D imaging to digital dermoscopy. Another useful aspect of this book is its attention to multiple medical specialties, including ophthalmology and gastroenterology, as well as dentistry and veterinary medicine. There are also relevant discussions of more modern issues such as HIPAA compliance and interfacing with digital platforms including social media. In summary, acquiring the knowledge contained within this book will lead to a quantum leap in photographic skills and expertise.

November 2020

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Preface

Hence the soul never thinks without a mental image.

"On the Soul", Aristotle (384 a. C.–322 a. C)

The line between the reality that is photographed because it seems beautiful to us and the reality that seems beautiful because it has been photographed is very narrow…

"The adventure of a photographer", Italo Calvino (1955)

I photograph what I do not wish to paint and paint what I cannot photograph.
"Man Ray (1977)"

Photography has been used in the medical field almost from its beginning. Doctors saw it clearly from the start: image is power. Shooting that first medical photograph was like the firing of a starting pistol that marked the beginning of the modern era of medical knowledge. Photography was the spaceship with which medicine and doctors would transcend in time. Medicine suddenly shifted from the subjective field of fine arts into objective photography-based evidence. Objectivity, that word that leaves a sweet flavor in a scientific mind; transcendence, another dear word. Both concepts materialized first by the invention of printing and later by photography, and both democratized knowledge, making it available to almost everyone regardless of distance.

But the image was more potent and far reaching because it overcomes common communication barriers: humanity shares a common language for reading images.

It all started as a game: curiosity had physicians photograph the bizarre, the all-that-is-not-me; then came the systematic imaging of every aspect related to health and disease. Calvino wrote in *The adventure of a photographer: "The minute you start saying something, 'Ah, how beautiful! We must photograph it!' you are already close to the view of the person who thinks that everything that is not photographed is lost, as if it had never existed.*" The beginning was at first just a Memory Game, where users tried to find the matching pairs. But the mind always plays funny tricks and those hundreds of images that pass in front of our eyes took us a step forward and patterns of recognition were soon part of our diagnostic schemes.

Hitchcock's psychological thriller Vertigo is what comes into mind when we hear that 14.58 million photos are uploaded per hour only on Facebook.

Humanity is becoming reduced to an image. But in medicine, numbers become irrelevant: it is quality that counts. Medical photographs need to be excellent if they are taken for teaching, getting second opinions, monitoring treatments, building libraries of images to feed algorithms, etc. and all brings us back to the our main goal: help patients.

Quality of image requires understanding basic concepts of photography and secondly, applying them to standardize images. Comparability is a must. Each specialty has developed its own guidelines; some more formalized than others. The ABCs for proper medical photography have been created or need to be improved.

Once the standards are met, the potential for using photography to improve medical care becomes infinite. Comparison, extrapolation, projections, monitoring, post-processing, diagnosing, pattern recognition, big data, and artificial intelligence, facial recognition: an avalanche of concepts come to mind, each opening a new door and then another one—a matrioska of possibilities just a click away from us.

No wonder many doctors become professional photographers. They spend their days looking at life and death through a lens, registering diseases and cures as photograms. Once trapped in this spiral of light, it is difficult to be free again.

But photographs are not restricted to family photo albums anymore: they are shared in the cloud. That medical information we have so zealously maintained out of the public eye is becoming accessible, voluntarily or not, to many: laypeople, government, hackers. Cybersecurity becomes an issue.

Photography is turning almost 200 years old. And the first patient´s photographs are being exposed in museum. How many years will it take to see our own patients be part of an exhibition? And how are we going to preserve all this iconographic material? What is the best way to store this enormous amount of information generated by the seconds? How should we teach future generations the concepts behind what seems to be a simple act of taking a picture? How do we cope with media obsolescence? Do we really need a sharp image to make a diagnosis? Will the future of medicine be so overtaken by image that we will treat photos? Is it correct to take and use these images just under the justification that “it is for your own good?”

The quest to answer some of these questions had me contact professionals from many fields: medicine, photography, philosophy, sociology, scientists, specialists in cybersecurity. Just because medical photography is more than registering for a health record, it ceased being a domestic issue: it is part of an interconnected and complex word, a new way of existing. Medical Photography is no longer a medical issue.

This book is just the beginning. I know and in fact hope many new facets that have not been dealt with of this largely neglected and still powerful imaging technique will enrich future editions. These two centuries of photography and its frenetic and continuous growth are an indication that we have not even close to the end: this is just the beginning of an amazing journey in the world of imaging.

Tarragona, Spain Paola Pasquali

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This book has seen the light thanks to a team effort.

To each and every author and coauthor that participated. Their dedication, commitment, time, and insight made this book possible. Thank you all!

To Juliette R. Kleemann—my Springer Editor—who believed in me. Her support and good advice have been paramount for this project.

To the infinite patience of Hemalatha Gunasekaran, from the Springer Editorial Team, who had to bear with stoicism my bombardment of questions.

To my neglected family. Sorry for the missed meals, parties, vacations, and conversations… Please accept a rain check: I promise to catch up!

Last but not even least, to my husband Ali. He makes every project a reality, every dream come true.

Contents

Part I History of Medical Photography and Its Ancestors

Part II Approaching the Subject

Part III Color in Medical Photography

Part IV Basic Concepts and Equipment

Part V Standardization in Medical Specialties

Part VI Beyond Conventional Photography

Part VII Preserving, Archiving and Publishing

Part VIII Deep Learning and Blurred Vision

Part I

History of Medical Photography and Its Ancestors

1

Medical Iconographic Representations in the Pre-photographic Era

Paola Pasquali

Contents

1.1 Introduction

Iconographic representation of disease has been present from the beginning of humankind. The first medical representations were probably not meant to be part of any educational material or to shape a body of categorized observations. These medical paintings, sculptures, and engravings probably reflected a simple observation of the body during disease processes. As such, they have helped us know which diseases were present in the past. Portraying healers practicing their professions was not part of the first representations of medicine. Iconographing healers came later probably to dignify the profession and to project an aura of professionalism in manner that physicians do nowadays.

Masks from Africa showing the impact of diseases like leprosy or yaws (Fig. 1.1), ancient Egyptian doctors taking care of teeth conditions, brick colored Greek vases with black paintings of sick people, *tumi* knives used in rituals, sacrifices, blood transfusions, amputations, cranial trepanations like those of Inca medicine with 90% survival are but some of the numerous examples of medical conditions representations in past iconography.

But the lack of reproducibility made each of these objects unique. Illustrations or sculptures were mere interpretations of reality and each copy included omissions and changes. Science needed medical imagery and written information that could be reproduced in large numbers to guarantee spreading of knowledge. This reproducibility needed to be low-cost and capable of generating identical copies. Spreading knowledge required numbers, quality, and similarity of details for each reproduction.

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Fig. 1.1 Mask Representing a Diseased Face, Guinea Coast, Nigeria, early to mid-20th century, wood and pigment. (Figure under Public Domain, from the The Yale University Art Gallery, donated by Charles B. Benenson, B.A. 1933, Collection Nr. 2006.51.295, CCBY)

Much of the preservation of medical information from Antiquity was the work done inside monasteries of the Middle Ages. Knowledge was hand written into manuscripts transcribed by monks. They were at those times among the few capable to read and write: scribes were an elite. But transcriptions are always interpretations. Small modifications were inevitably added, especially when copying paintings. Changes could also be included for social, political, or religious reasons. The copyists of the European Middle Ages and the Renaissance were the distant and more professional descendants of those scribes of the nascent Christianity that Christ called "snakes, offspring of vipers" (Mt 23: 1–33) for their frequent adulteration of the Scriptures.

For Cazort M [1], two major developments happened at around 1500 that affected scientific illustration into what became in present time:

1. **A drastic change in scientific methodology**. Up until then, nobody refuted those principles of authority inherited from old masters, so-called the Writings of the Fathers. The sole pretention could be considered heresy. Aristotle, Plato, or Galeno's ideas on science and medicine were repeated one generation after another until the Renaissance. From this point forward, man tried to understand and dominate nature, to question it. The old principles started to be examined, and these were mostly rejected. Natural phenomena were analyzed and theories were born from observations. Humanism is the philosophical and ethical stance that emphasizes the value and agency of human beings, individually and collectively, and generally prefers critical thinking and evidence (rationalism and empiricism) over acceptance of dogma or superstition. Vesalius [2], considered the father of human anatomy, wrote and published his findings that were the result of direct observation and not hand-downs from Galeno's work which had mostly been done on other animal species and assumed as identical to humans. Before the Renascence, nature was explained using myths but from this point on, men stopped being afraid of nature. Medieval conceptualism gave way to empiricism despite the reactions of the traditionalists. Du Bois, teacher of Vesalius, accuses him of "madness" for his attempt to discredit Galenic teachings. Vesalius authored *De humani corporis fabrica* (On the Fabric of the Human Body, 1543), a milestone that marked a huge change toward the development and knowledge of modern medicine (Fig. 1.2).

   This shift in scientific methodology signified the birth of modern science.
2. **Illustration was recognized as integral to knowledge dissemination**. Art and science confluence in their interest for anatomy. Vesalius had the illustrations made by Jan

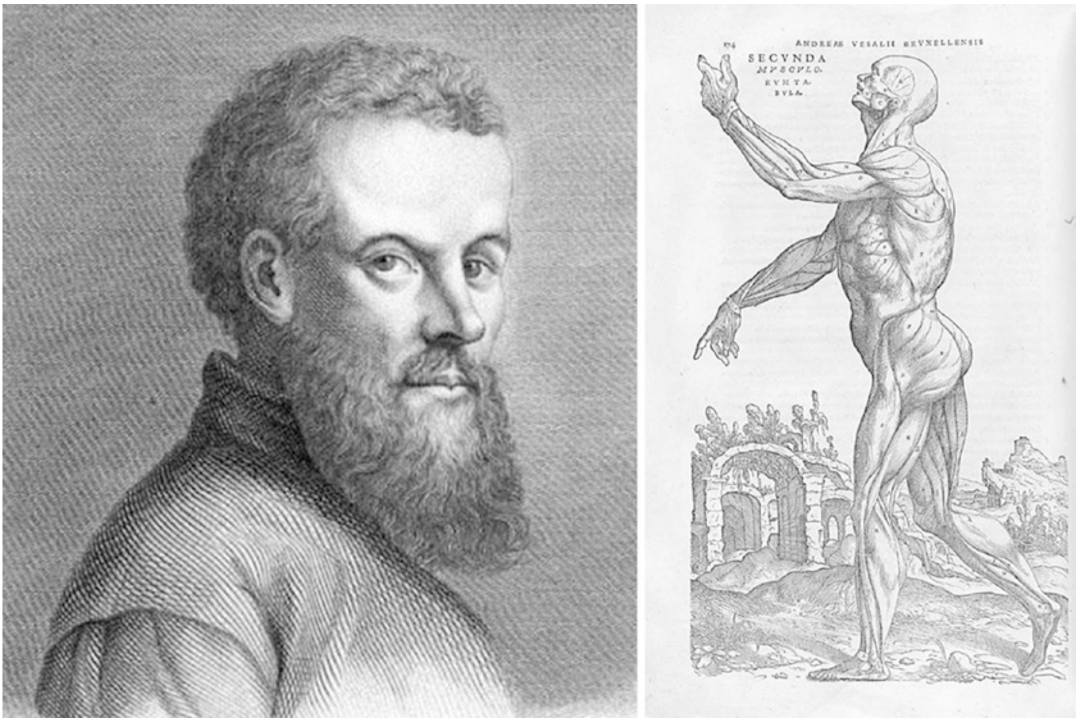

Fig. 1.2 Andrea Vesalius, Flemish anatomist (left) and one of the anatomical illustrations (right) from his works De humani corporis fabrica (1543) (Figure under Public Domain, from Portrait of Andreas Vesalius (1514–1564) A. Vesalius, De humani corporis fabrica libri septem. Wellcome Collection. CC BY)

Steven van Calcar [3], a German born Italian painter that trained with Tiziano. The printing was done from engravings on wood (xylography). Vesalius innovation was not just on science but also on editorial concepts and its aesthetics [4]. Leonardo studied anatomy as a scientist [5] (Fig. 1.3) and combined the study of structure with the study of function. Both Vesalius and Leonardo worked on human dissection.

The mathematics behind perspective as we know it today was also born in Italian Renaissance. The new conventions were applied both to anatomy and architecture [6]. Leonardo's Vitruvian man (*L'Uomo di Vitruvio*) with its ideal body proportions (Golden ratio) is one of the best example of this merging of concepts. The use to represent progression development of living organisms became another theme present in illustrations, both in anatomical plaques as in botanical ones [1].

1.2 The Printing Revolution

By around 1450, less than 8% of the population in Europe knew how to read. Gutenberg's printing system democratized reading and disseminated knowledge like never before [7]. Printing had an impact on the spreading of knowledge, and medicine was not exception to this revolution.

The search for verisimilitude has always being a concern to both artist and scientists. Printing guaranteed spreading of information but not necessarily its credibility. Versatility related to the origin of the source of information and if the source was an antique text or a word-of-mouth, it could result in an erroneous interpretations as was the case of Albrecht Dürer's rhinoceros representation which was copied for centuries as a "a real rhinoceros" [1, 8] (Fig. 1.4).

One fundamental practical problem was how the scientist could make sure that the "artist" depicted what was seen or discovered by scien-

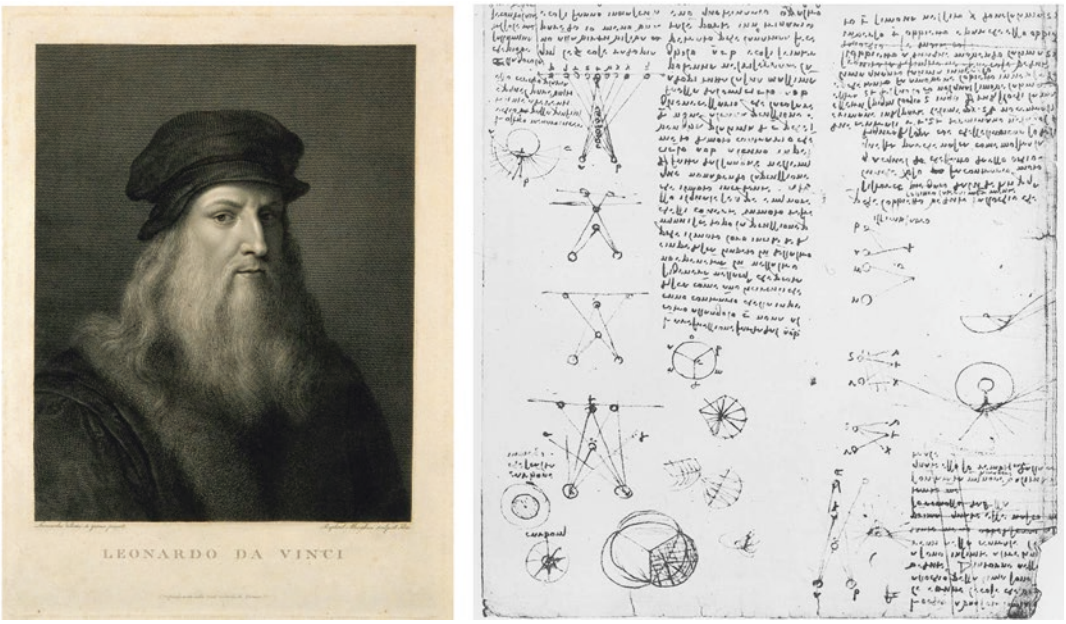

Fig. 1.3 Leonardo da Vinci (1452-1519) (left) and the manuscript on eye and vision (right) (Figure under Public Domain, from Leonardo da Vinci. Line engraving by R. Morghen after Leonardo, and Leonardo da Vinci. On the eye and vision. Wellcome Collection. CCBY)

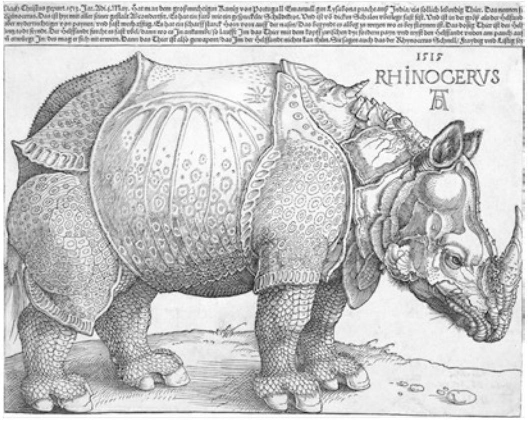

Fig. 1.4 Albrecht Dürer's rhinoceros (1515) (Figure under Public Domain, from The Rhinoceros, Woodcut, Gift of Junius Spencer Morgan, 1919, The Metropolitan Museum of Art, CCBY)

tists in an "objective" manner. Some skilled scientists did the illustrations themselves, but, in most cases, they needed to relay on an artist, giving place to a new re-interpretation. This artist's mediation was not always negative as it could be used to emphasize certain aspects and eliminate confusing or unnecessary features [9].

Methodology gave rise to scientific collections which became the first museums. One issue was the selection of what was a representative of normality. Very soon, there were illustrations of the deviant and illustrations for the normal, a trend that came down to the era of photography.

Another convention that was later incorporated into photography was depicting facial expressions as a mean to "read the mind" and understanding human soul (Fig. 1.5). These expressions of emotion were often related to animals as found in Giovanni Battista della Porta (1535–1615) [10] a pioneer in the use of *camera oscura* and author of "*De Humana Physiognomonia*". He based his non-scientific idea that physical features could be tied to physiological and moral traits and explored the hidden "sympathies" between animals and humans (Fig. 1.6).

In spite of recognizing the importance of images in describing nature, the first medical illustrations and later photographs have always used text to emphasize, explain, and point out relevant information. The discussion of the complex relationships between image and text goes

Fig. 1.5 Henri Testelin (1616–1695), the expressions (1696) (Figure under Public Domain, from The expressions, Etching, Rogers Fund, 1968, The Metropolitan Museum of Art, CCBY)

beyond the scope of this chapter; texts in medical images have always been there to help the viewer look selectively and reduce other interpretations which are possible even when the "objective" means of imaging like photography came into use.

Just as perspective improved imagery of medical illustrations, tri-dimensionality added realism. One example is found in a book titled Toshin Seiyo (*The essentials of smallpox*) written by Japanese doctor Kanda Gensen (c. 1670–1746). The uniqueness of this book lies in the use of texturized pages which give a realistic aspect to a disease that frequently left disfiguring scars (Fig. 1.7) [11]. Wax *moulage* (molds) is another example of this search for tri-dimensionality as applied for scientific bi-dimensional knowledge.

During the eighteenth century, medical illustration moved away from beautified images into "warts and all" depictions (Fig. 1.8). The beautification of images played a role in what Kemp M. calls "the rhetoric of imagery" [8]. These new representations worked as visual pointers to the claim of depicting "real life" and were part of establishing an image of civility to the anatomist's profession and "its claim to reveal the observed truth." This style was gradually replaced by a more "objective" "non-style" anatomical plate whose perfect expression is found in the nineteenth-century Gray's anatomy.

In 1831, Jean-Baptiste Marc Bourgery began to work on what ended up as an eight-volume masterpieced *Traité complet de l'anatomie de l'homme comprenant la médecine operatoire* [12]. The illustrations were done by artist Henri Jacob together with a team of painters. Jacob had been a student of the renowned French painter Jacques-Louis David. The engravings were directly painted on stone (lithography), with ink and greasy pencils (Fig. 1.9).

LIBER SECVNDVS. 29

De Capite. Cap. 1.

NOS cum Ariſtotele totum id caput vocamus, quod collo ſubſtentatur. Primo integrum conſiderabimus, poſt eius partes, frontem, oculos, ſupercilia, & reliqua. Galenus capitis conſiderat quantitatem, & formam, quantitatis varietas in magnitudine, & paruitate conſiſtit; loquemur primo de quantitate.

Hac tabella maximum bubonis caput, & Vitellij Cæſaris vaſtum exprimitur, vt ex marmorea ſtatua, quæ in Muſæo Hadriani Spataſori patritij doctiſſimi. & rerum antiquarum ſtudioſiſſimi aſſeruatur, excipi curauimus.

Maximum Caput.

POlemon, & Adamantius in eorum Phyſiognomonicis, caput, quod magnitudine exuperat, obtuſi, & indocilis hominis argumentum dicit. Albertus animalium libro, Enorme caput, quod præ ſui magnitudine ad humeros vergit, ſenſu, & virtute carere dixit: & Paulo poſt. Immenſam autem ſtultum, ſtolidum, & vehementer indocile. Ariſtoteles libro de ſomno. & vigilia, ait. Qui minimo plus in caput extumuerint, ſomniculoſi ſunt, nam quo amplius eſt receptaculum, eo plus item capiat neceſſe eſt. In nanis, ſiue pumilionibus vaporum multitudinis vis adcaput ſurrigitur, quoniam grandius membrum alimenti amplius requirit, quod verò copioſe ſcandit, copioſe remeet conſequens eſt, ſed lentius, quia inſitus calor vim tantum ſublatæ euaporationis breui percoquēdo nequit conficere. & in ſuis Phyſiognomonicis in figura ſonnolenti, tribuit ei ſuperiora maiora, ideſt caput. Capitis magnitudo materiei potius abundantiam, quam virtutis excellentiam indicat. Ego ad aſinos referrem, quorum caput grande, & ineptiſſimis ſunt moribus, ſtolidi, degeneres animo, timidiq;. Inter aues ad nocturnas, vt noctuas, & bubones, quæ omnes capita enormia magnitudine habent, ex otio prodeuntes, è pedibus exeunt, nimio pondere capitis detentæ. Ouidius de Aſcalapho in bubone mutato.

Inro-

Fig. 1.6 Maximum Caput, from Giambattista della Porta (1586) (Figure under Public Domain, from De humana physiognomonia, libri IIII, page 29, National Library of Medicine, CCBY)

Fig. 1.7 Hand-drawn and textured page from a rare Japanese treatise on smallpox—The Essentials of Smallpox, ca. 1720, written by the Japanese doctor Kanda Gensen (1670–1746). (Figure under Public Domain, from Toshin seiyo, Wellcome Collection. CC BY)

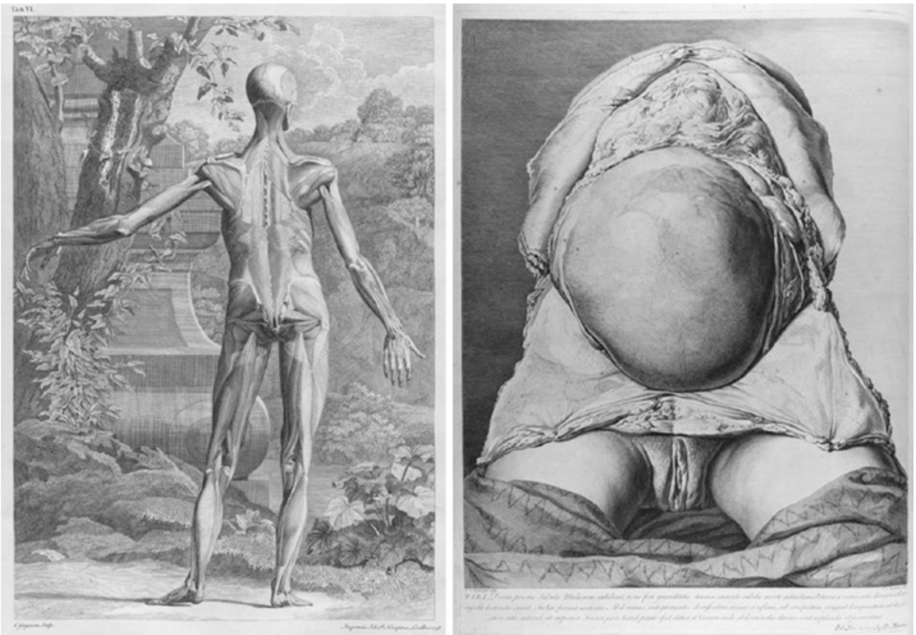

Fig. 1.8 On the left, a beautiful anatomical illustration from Bernhard Siegfried Albinus (1697–1770). The setting reminds a painting with the body posing over a picturesque background. It represents a "beautified" anatomical representation. The right image is from Anatomia Uteri Humani Gravidi (1774) by William Hunter. It is a direct portrait, "wart and all" (Figure under Public Domain, from Anatomia uteri humani gravidi tabulis illustrata, Hunter William, The National Library of Medicine. CC BY)

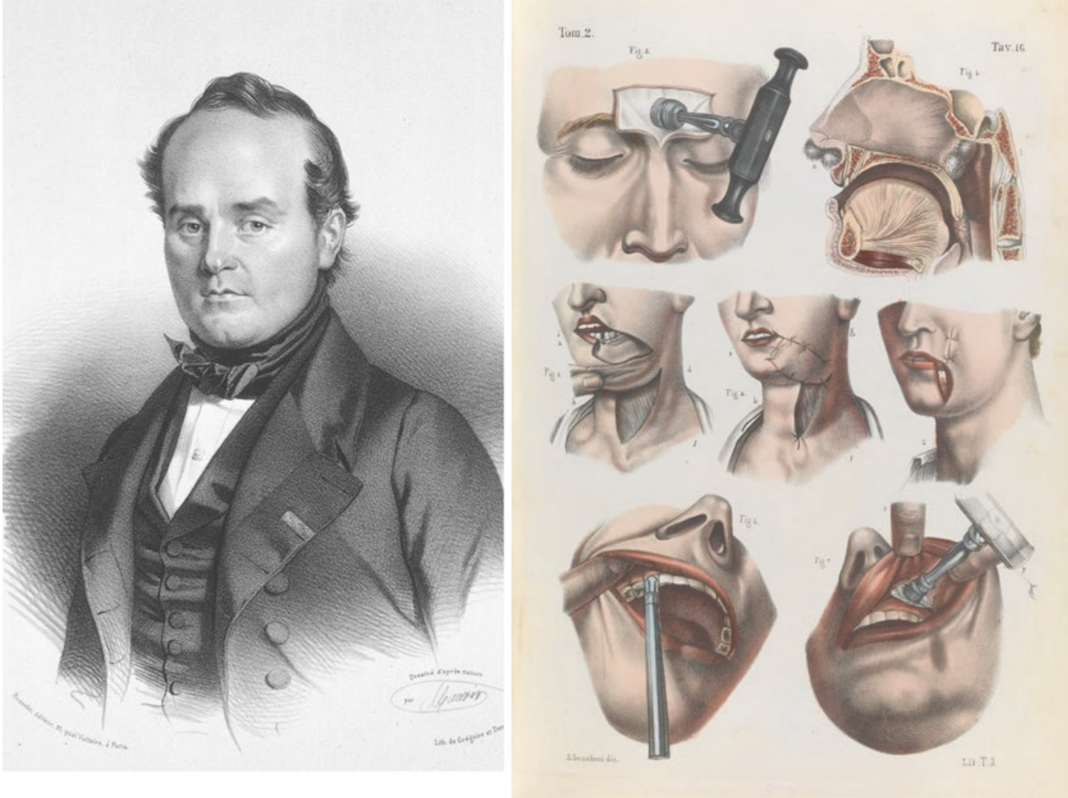

Fig. 1.9 On the left, the litography portrait of the anatomist Jean-Baptiste Marc Bourgery (1797–1849) by Maurir (Figure under Public Domain, Wikipedia Commons, http://resource.nlm.nih.gov/101408861 CCBY) and on the right, an anatomical plate on the perforation of the frontal sinuses, a lithography by Bourgery himself (Figure under Public Domain, from Anatomy Icnonography, 1841, Tomo II, Plate 16, Bourgery and Jacob, Wellcome Collection. CCBY.)

1.3 Scientists Borrowing Artist's Conventions

There are many examples of this continuous "borrowing from" between artists and scientist which still continuous today. In 1835, Dr. Peter Parker, a reverend and surgeon from Yale University, established the first American hospital in Guangzhou (China). He asked artist Lam Qua (1801–1860) to paint a series of portraits illustrating patients with large tumors [13] (Fig. 1.10). These paintings were first done on rice paper, but later on they were done on oil canvas. The style followed conventions taken from European paintings. Later, Lam Qua became the first Chinese portrait artist to expose in the Western world (Fig. 1.11). Étienne Pariset (1770–1847)—a French physician and psychiatrist associated with the Salpêtrière Hospital—did research on infectious disease in Syria, Egypt (he was a good friend of archaeologist Jean-François Champollion, who deciphered hieroglyphs) [14], and Spain. In his book titled *Observations sur la fièvre jaune faites à Cadix* (1819) includes a series of illustrations that show the deteriorating changes on a patient with yellow fever. This sequence of images follows a convention later used in photography for monitoring or "before and after" photographs (Fig. 1.12).

Posing of early medical photography was another convention inherited from the early forms of medical illustration [15]. Figure 1.13 shows the awkwardness of posing as in the attempt to balance two demands: a heroic and dignified pose appropriate for a war veteran and that of a medical image to show a lesion.

Fig. 1.10 (Lam Qua /1801–1860) paintings from the Peter Parker collection. Left: portrait number 7, showing a woman with a tumor on the bridge of her nose. Right: Portrait 32, man with amputated arm (Reproduced with permission from the Harvey Cushing/John Hay Whitney Medical Library, Yale University)

Fig. 1.11 Lam Qua working in his studio (c.1868) photographed by John Thomson (Figure under Public Domain, from the Wellcome Library, London, Iconographic Collection, Photo number L0055677, http://catalogue.wellcomelibrary.org/record=b1177718, CCBY)

Fig. 1.12 Illustration from the book Observations sur la fiévre jaune, faites á Cadix, 1819 by Etienne Pariset. (Figure under Public Domain, from the Wellcome Collection https://wellcomecollection.org/works/neg7rqg6. CCBY)

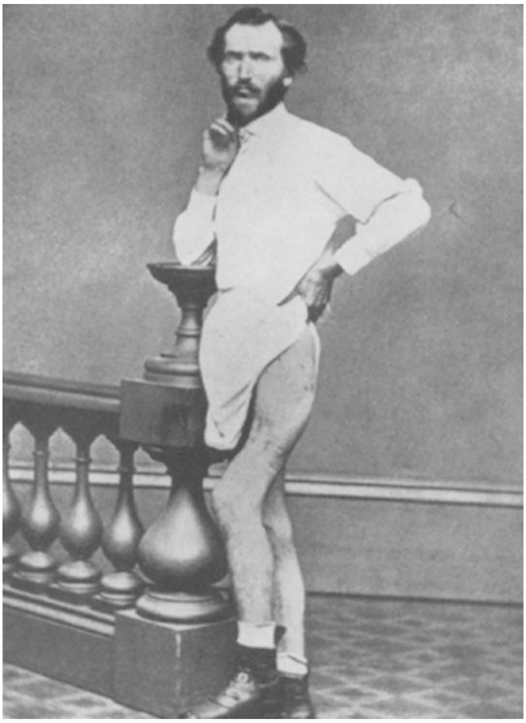

Fig. 1.13 Posing the Subject of Early Medical Photography by Chris Amirault. Reprinted from Discourse: Journal for Theoretical Studies in Media and Culture, Vol. 16, No. 2. Copyright © 2 Wayne State University Press, with the permission of Wayne State University Press

1.4 Drawing and Advertising

The University of California, San Francisco (UCSF), maintains a collection of 400 health-themed woodblock prints from nineteenth-century Japan. The collection includes drug advertisements, treatments for contagious diseases, and human anatomy. Their period of production extends from around from the late Eado period (1603–1868) to the early Meiji period (1868–1912) which corresponds to Japan's beginning to open to Western world. They provide evidence for the effect of Western medical science on local beliefs and practices (Fig. 1.14). Medical illustrations were used to teach but also had the advantage of making books more attractive and competitive [8].

The following chapters will deal with the fascinating history of medical illustration in two medical specialties: dermatology and veterinary. They are not the soles with a rich heritage: ophthalmology, gynecology, and many others could fill entire books. All together are a part of the ancestors of photography and their need to leaving a visual testimony of disease.

Fig. 1.14 Left: Hashika yōjōben (advice on caring for measles patients) medical woodblock print by Utagawa Yoshitora, late Edo and early Meiji 19th-century period, Japan (Figure under Public Domain, UCSF Japanese Woodblock Print Collection, CCBY) Right. Woodblock technique, Ukiyo-e workshop by David Monniaux, Tsukuba, Japan (Figure under Public Domain, Wikimedia Commons, CCBY)

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The Dermatology Photographic Ancestors

2

Xavier Sierra

Contents

2.1 Introduction

Dermatology is a visual discipline. You cannot learn dermatology without the help of images. No matter how good and detailed is a clinical description done, it is essential to see it represented graphically in order to understand it well [1].

Obviously, illustrating a medical book before having the photographic technique was not easy. It was necessary to find an artist capable of making a clinical illustration with artistic quality for which it was necessary that he/she understood what was needed to be transmitted. Understanding the concept and representing it with quality was fundamental for making the correct diagnosis. It was not always easy to find profane artists in medicine who reflected the symptomatology well. At first, the most used techniques to reproduce diseases were drawings. Shortly after, the practice of watercolor was extended since it was faster to make and showed different tones that gave a much more vivid and real representation of colors. Some collections of great artistic merit are still preserved today. Oil painting was much less frequent as it was more expensive and slower to apply.

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2.2 The Clinic Represented in the Painting (Seventeenth to Eighteenth Century)

It is generally considered that the birth of dermatology as a medical specialty took place at the beginning of nineteenth century; however, curiosity about the disease started much earlier. In the Royal Courts of the seventeenth century, for example, it was customary to give shelter to people with disfiguring medical conditions. They were displayed in front of the court: their disease became a part of a show, a rarity worthy of being exhibited. Achondroplastic or pituitary dwarfs, cretins, males with hypertrichosis lanuginosa, bearded women, or other pathological states were part of buffoons or servants and exhibited as whims of nature. Many of them were painted to perpetuate the observation of such anomalies. Suffice it to recall the jesters of Velázquez or Van der Hamen, some paintings of Sánchez Cotán, Italian female from the first Baroque period Lavinia Fontana (Fig. 2.1), or paintings of the castle of Ambras. The taste for the odd, for the monstrous, and for the shocking was a characteristic of the Baroque era, and these collections of human pathology gave prestige to those who possessed them [2].

Fig. 2.1 Portrait of Tognina Gonsalvus (b. 1580) painted by Lavinia Fontana (1552–1614). In this painting, Antonia (Antoinette or Tognina)'s hypertrichosis was exposed rather than masked. Collection of Chateaux de Blois. (Figure under Public Domain, Wikimedia Commons, CCBY)

Not all the pathological cases were to be found with the courts, and still artists managed to perpetuate their existence. This is the case of Magdalena Ventura, a woman from the Italian Abruzzo who presented a striking hirsutism, probably secondary to a tumor or adrenal hyperplasia. Jusepe de Ribera (José de Ribera, Josep de Ribera, also called *Lo Spagnoletto*; around 1591–1652) was a Spanish-Italian Tenebrist painter who recorded her case in a painting called "The Bearded Woman" under the commission of his regular patron, Fernando Afán de Ribera y Téllez-Girón, Duque of Alcalá and Viceroy of Naples. The latter had heard of the existence of this woman and brought her to court to be painted. She was represented breastfeeding her youngest child, as a visible demonstration of her motherhood and not an intersexual state. The detailed clinical history that was attached to one side of the chart demonstrated the scientific interest in perpetuating the case (Fig. 2.2).

2.3 The Illustrations in the Dermatology Treatises (1798–1850)

Leaving aside the aforementioned representations of the disease in the painting and that were specific cases, the representation of the disease posed very different problems. The idea was to include images in books destined to transmit medical knowledge, and therefore reach a large distribution, which entailed many technical and economic difficulties. Until the eighteenth century, only some engravings and xylographs tried to alleviate the iconographic shortage of this period. This would explain why we do not find any image in the works of Turner (1667–1714) [3], Plenck (1735–1807) [4], or Chiarugi (1759–1820) [5]. The edition of Sauvages's work (1706–1767) [6] included four colored engravings.

Fig. 2.2 Portrait of Magdalena (Maddalena) Ventura with Her Husband and Son, painted by Ribera in 1631. Prado Museum in Madrid. (Figure under Public Domain, Wikimedia Commons, CCBY)

Fig. 2.3 *Ichtiosis Faciei* (Willan and Bateman). (Figure under Public Domain, from the Wellcome Collection https://wellcomecollection.org/works/mxsykwmy/items?canvas=1&langCode=eng&sierraId=b30450007. CCBY)

The first profusely illustrated work coincides with the first great dermatological classification. Robert Willan (1757–1812) classified the diseases of the skin according to the type of elementary lesions. He is considered a pioneer in morphology. Willan was also the first to recognize the importance of illustrations in the description of skin disorders. From 1786, he began to collect drawings accompanied by descriptions of certain skin conditions. Later, he perfected the graphic representations, many of which were engraved on copper plates.

A great idea was taking shape: to gather illustrations and comments for his textbook, which would make its classification much more comprehensible and didactic. He created the first atlas of skin diseases containing color picture. The work was published between 1796 and 1808, in four parts [7]. For the first time in history, a textbook had 30 colored illustrations by hand. The plates had been made by various artists, and Willan himself had supervised and retouched them. The drawing was primitive, and could not transmit all the richness of the clinical image, but it had its utility.

In his book *On Cutaneous Diseases*, the illustrations present only four of the original eight orders of the system since Willan died before being able to complete his work. But his disciple Thomas Bateman (1778–1821) completed the willanist doctrine from the dermatological point of view [8]. He had the property of his master's engravings, and was able to complete the iconography, adding some new drawings that he made himself, with the help of the engraver Stewart. The atlas [9] was published between 1814 and 1817. Steward's artistic talent was evident: the new illustrations were considerably better than the ones found on the earlier version (Figs. 2.3 and 2.4).

The Portuguese doctor and botanist Bernardino António Gomes (1769–1823)—with willanista orientation—published a treatise that included

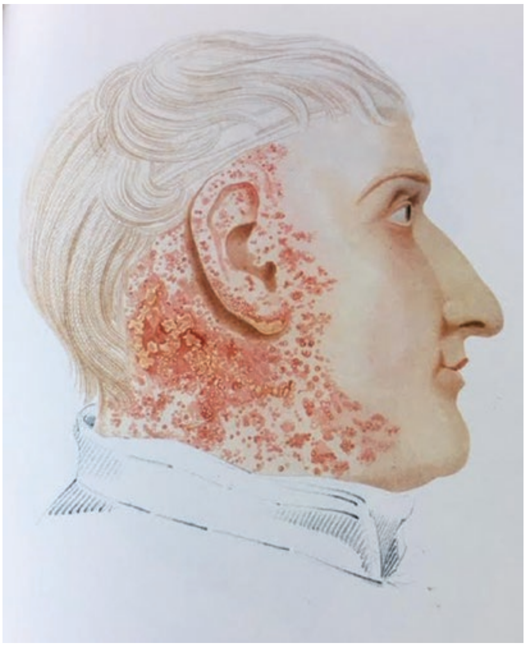

Fig. 2.4 *Eczema rubrum* (Willan and Bateman). (Figure under Public Domain, from the Wellcome Collection https://wellcomecollection.org/works/mxsykwmy/items?canvas=1&langCode=eng&sierraId=b30450007. CCBY)

Fig. 2.5 Bernardino Gomes, *Preto Bubas* (1820). *Preto com Boubas*, from the book *Ensaio dermosographico ou succinta esystematica descripcão das doenças cutaneas* (1820) by Bernardino Gomes. (22 × 13 cm)

two sheets of extraordinary quality made with an engraving technique called chalcography that uses copper plates for printing and illustrations. The drawings were done by J. Paltiere of Rio de Janeiro and the engraving by Van den Berghe in Paris [10] (Fig. 2.5).

Around the same period, at the Saint-Louis Hospital in Paris, Jean-Louis Alibert (1768–1837) was attempting to generate his own classification of skin diseases, based on botanist' Linnaean method. In 1806, before the appearance of the last volume of Willan's work, Alibert published his *Description des maladies de la peau* that included 53 hand-colored engravings [11]. Alibert was probably unaware of Willan's work, reason for which he considered himself to be the first to use illustrations as a didactic complement. The plates on Alibert's book had a large size (36 × 56 cm) and extraordinary quality, exceeding in clarity and detail those of Willan and Bateman's (Figs. 2.6 and 2.7). In the work second edition, made in Brussels, the illustrations were perfected, increasing in number and colors [12].

Fig. 2.6 *Syphilide pustuleuse en grappe,* from the *book Description des maladies de la peau* by Jean-Louis Alibert (1806) (Figure under Public Domain, Wikimedia Commons, CCBY)

Fig. 2.7 *Mycosis fongoïde*, from the book *Description des maladies de la peau* by Jean-Louis Alibert (Figure under Public Domain, Wikimedia Commons, CCBY)

In the work published in 1835, the author includes his famous *Arbre des dermatoses* (Tree of dermatosis), symbol of his classification system [13] and seed of what we know today as infographic (Fig. 2.8).

On a more serene and objective tone are the illustrations found in the work of Pierre Louis Alphée Cazenave (1795–1877), disciple of Laurent-Théodore Biett, in which the colors are less bright and their realism closer to reality [14] (Fig. 2.9). One of his illustrations is very curious and shows various skin diseases on the same human body. This image, which had been used in the few representations of medieval skin diseases, is unusual for the nineteenth century (Fig. 2.10).

Pierre François Rayer (1793–1867) chose to group all affections of the same group on the same plate [15]. Probably, in addition to the nosological interest that it may represent to gather the same category of injuries, the intention was to reduce editorial costs. They were published in the form of atlas, as a separate complement to the text. The

Fig. 2.8 Jean Louis Alibert's *Arbre de dermatoses* (1833) (Figure under Public Domain, Wikimedia Commons, CCBY)

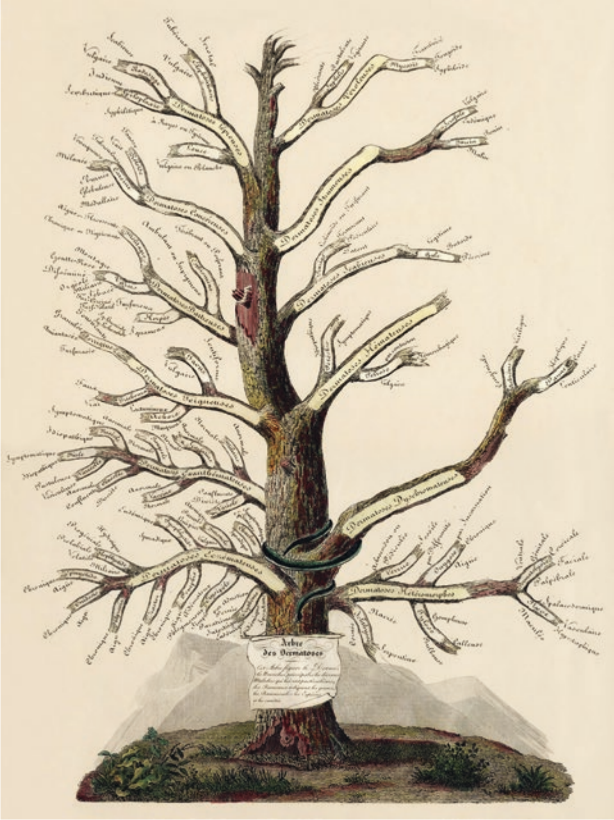

Fig. 2.9 *Impetigo* (Cazenave, 1856) (Figure under Public Domain, from the Wellcome Collection, https://wellcomecollection.org/works?query=fd99ccbv&search=images. CCBY)

result was a set of 22 illustrated plates stuffed with tightly mottled illustrations, which included more than 400 figures in total. Only the patient's affected part was represented, in a very limited manner, making the image depersonalized, reifying the subject (Fig. 2.11) It objectified the subjects by treating them as a collection of different objects. The preliminary drawings were done by Young and Prêtre, while Forrester and Langlois were responsible for the engraving in color using the technique of points engraving (chalcography). A later version published in Brussels was with hand colored lithographs [16].

In England, Sir William J Erasmus Wilson (1809–1884) [17] published an atlas with 92 color illustrations based on dermatological and venereological conditions. The highlight of this work was the style of the lithographs, made by William Bagg, an artist of clear pre-Raphaelite tendency. The sharpness of the lines, the vivacity of the colors, and the tender morbidity that permeates the characters (characteristics of the English pre-Raphaelite painting) define the unequivocal style of these excellent dermatological plates (Fig. 2.12).

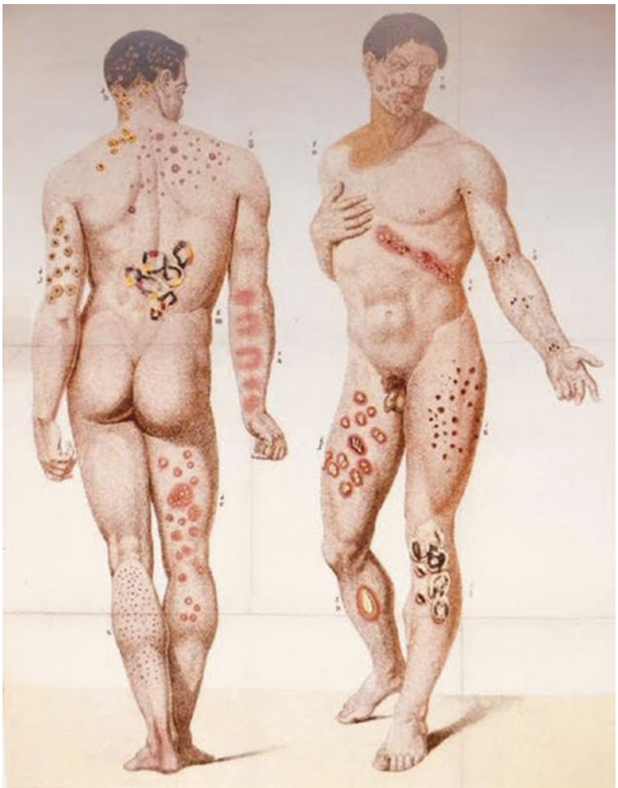

Fig. 2.10 Cazenave-Schedel, Alphée Cazenave & H.-E. Schedel, Ordres des maladies de la peau (1833) 29.5 × 22 cm. From the book *Abrégé pratique des maladies de la peau, d'après les auteurs les plus estimés, et surtout d'après des documents puisés dans les leçons cliniques de M. le docteur Biett* (Figure under Public Domain, from the Wellcome Collection https://wellcomecollection.org/works/rkduduxt/items?canvas=1&langCode=fre&sierraId=b29295233. CCBY)

Fig. 2.11 Measles rash, from the book *Traité théorique et pratique des maladies de la peau, avec un atlas* by Rayer, Pierre François Olive, 1835 (Figure under Public Domain, from the Wellcome Collection https://wellcomecollection.org/works/u3bukzzk. CCBY)

Fig. 2.12 *Acne Rosacea*, from the book William J Erasmus Wilson, 1857 (Figure under Public Domain, from the Wellcome Collection https://wellcomecollection.org/works/qa4bdwmc. CCBY)

Fig. 2.13 *Icthyosis hystrix* (Hebra), diseased skin on the neck, back, arms and hands of a young woman suffering from icthyosis hystrix. Chromolithograph by E. Burgess (?), 1850/1880? (Figure under Public Domain, from the Wellcome Collection https://wellcomecollection.org/works/hy6cy62j. CCBY)

2.4 Dermatological Iconography of the Vienna School

In the mid-nineteenth century, Ferdinand von Hebra (1816–1880) created in Vienna an exceptional school that revolutionized dermatology. To illustrate his book [18], but also to create an archive of images where he could preserve all the various clinical cases observed by him, he hired doctors who were also good artists. It was a great sacrifice, since we must bear in mind that Hebra's position as a professor of skin diseases was honorary. He believed in the value of preserving high-quality images of a large variety of skin conditions observed by them (Figs. 2.13 and 2.14).

One of the most outstanding medical artists of the Vienna school was Anton Elfinger (1821–1864) and Carl Heitzmann (1836–1896) [19]. Elfinger had studied painting with Viennese painter Matthias Ranftl, known for his portraits and historical paintings, and with the famous

Fig. 2.14 *Herpes zoster Faciei et Capillitii* from the *Atlas der Hautkrankheiten of* Hebra, Ferdinand, Ritter von, 1816–1880

painter Leopold Kupelwieser at the Academy of Fine Arts in Vienna. But Elfinger's father, who was a pharmacist, wanted him to study medicine. After graduating, he entered the department of Hebra and began to work incessantly, with very precarious economic conditions, making hundreds of watercolors and drawings and, later, wax molds. The Slovenian Carl Heitzmann had first studied medicine in Budapest and later in Vienna, where he graduated in 1859. It is not known that he had a special artistic training, like Elfinger's. In spite of this, he had an innate talent and made very meritorious watercolors, although in a smaller number and of less quality than Elfinger [20]. His younger brother Julius, a doctor himself, also contributed making works for Hebra's collection (Fig. 2.15).

The illustrations of Hebra's Atlas were really opulent. Some, almost life-size, were reproduced in four-colored lithographic plates. Each of the images was protected by a transparent cover with a pen-made lithograph, which highlighted the outline of the lesions and included numbers to identify the text comments.

Fig. 2.15 *Lupus erythematosus*. Watercolor by Anton Elfinger (1843) (From Fatovic-Ferencic S., Plewig G, Holubar k. Skin in Watercolors. Viena. Blackwell Pub. 2003. p. 95)

The high artistic level of the Viennese school and its intimate link between medicine and art is manifested in a precise and detailed style that we could fit within the tendency of post-Romantic realism. Although the illustration focused on the diagnostic traits that allow classifying the disease (nosology is the maximum objective in Hebra's work), it was not obviated reflecting the patient's nonmedical features: his/her way of dressing, social class, origin, and religion (some patients appear with kippah, a seamless cap worn by Jewish men). This was due to the belief that certain details on the patient's environment could be valuable in making the correct diagnosis; on the other hand, there was a total lack of modesty in specifying certain patient's data. Nowadays, respect for patient's privacy acquires an extraordinary importance, and every image must guarantee the patient's anonymity, but in Vienna in the second half of the nineteenth century, doctors were more concerned with demonstrating the veracity of their assertions. Who could assure that an anonymous patient was not excessively idealized, or even invented? To avoid doubt, the patient data was frequently revealed with a profusion of details unthinkable today, with the intention that anyone could verify the accuracy of the diagnosis or the effectiveness of the treatment. It was not unusual to quote an individual's name or even his address, when commenting on his medical history. This justified the return to the personalized portrait in the dermatological iconography.

2.5 The Dermatological Iconography in Spain

In Spain, it can be said that dermatology was born with José Eugenio de Olavide (1836–1901), a doctor from Madrid who, after training in Paris [21], took charge of skin diseases in San Juan de Dios Hospital in Madrid. The need for preserving in his memory the clinical details of the cases he had seen led him to make plaques of cutaneous diseases, helped by one of his collaborators Hernando de Benito y Castelo.

Fig. 2.16 *Herpétide escamosa (Pitiriasis rosada)* from the *Atlas de la clínica iconográfica de enfermedades de la piel o dermatosis by* Doctor Don José Eugenio de Olavide Landezábal (1836–1901). Today it would probably be diagnosed as a psoriasis of the scalp. (Private collection Dr. Xavier Sierra)

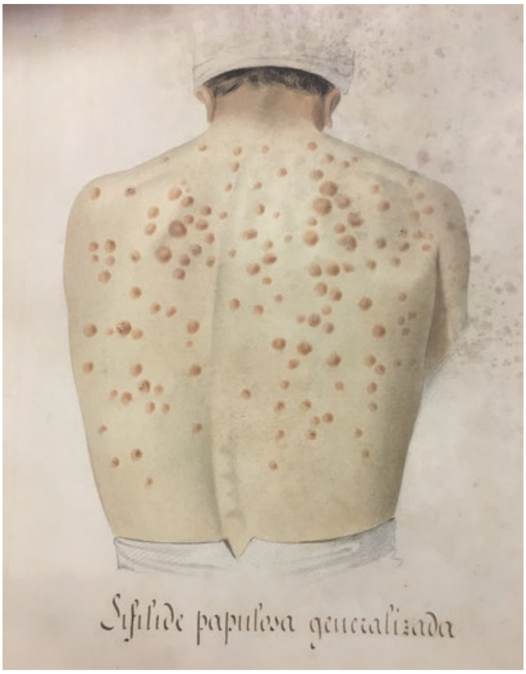

Fig. 2.17 *Sifílide papulosa generalizada*. Watercolor from Museo Olavide. Madrid (Permission from Museo Olavide, Madrid). (Photography by Sierra X with permission Museo Olavide)

Soon after, he had the idea to publish these experiences and teachings in the form of a book, arranging the material from his personal observations in order to help a better understanding of dermatological diseases. The treatise was entitled *Dermatología general y Atlas de la clínica iconográfica de enfermedades de la piel o dermatosis* and appeared in the form of fascicles between 1871 and 1880 [22]. This meritorious work was finally bound into two volumes and includes a textbook and a rich iconographic Atlas. Acevedo's illustrations, drawings, and lithographies of cutaneous lesions showed a myriad of details and precision (Figs. 2.16 and 2.17).

The work of Olavide became the most emblematic work of Spanish dermatology and became a mandatory point of reference for future dermatologists [23]. Its scientific value is considerable and one can see in a clear interest in searching for the etiology [24]; however, one of the difficulties he had was in regard to diffusion: the iconographic richness and large size of its pages (in-folio) (Figs. 2.18 and 2.19) made this work considerably expensive, which made that many of its possible readers, such as doctors or medical students, could not acquire it. It could only be found in libraries and official institutions. In fact, if it had not been for the official support of the Minister of Public Works of that time, Dr. Ruiz Zorrilla, it could not have been published at all.

Another outstanding work of the second third of S. XIX is that of the military doctor Diaz de Benito, on venereal diseases. Its careful edition included 90 lithographs, which were accompanied by their corresponding medical histories. The illustrations depicted in full detail cutaneous lesions caused by primary and secondary syphilis as well as the destruction of syphilitic gums and fetuses affected by the disease.

Shortly after the appearance of Olavide's work, Professor Joan Giné i Partagás (1836–1903), from the Surgical Clinic of Barcelona,

Fig. 2.18 Large format double page from the book *Atlas de la clínica iconográfica de enfermedades de la piel o dermatosis* by Doctor Don José Eugenio de Olavide Landezábal (1836–1901). (Private collection Dr. Xavier Sierra)

decided to publish his *Tratado clínico-iconográfico de Dermatología Quirúrgica*, a simpler work affordable to most students and doctors in practice. The books (five volumes) were made of transcriptions of his classes. Under the generic title of *Lecciones de Clínica Quirúrgica*, they comprised dermatology, venereology, oncology, phlebology, and traumatology [25].

The first volume was dedicated precisely to dermatology. In his prologue, Giné admits to have been influenced by Olavide's work, which he referred to as a "colossum." After the prologue, they started corresponding and expressing mutual recognition. Giné's book is accompanied by iconographic plates grouped at the end of the book. There were about 17 engravings lithographed by the printer named Vda. Labielle after Ignasi Carbó and Enric Castells's drawings [26] (Fig. 2.20). The first three sheets, not colored, were dedicated to structural and microscopic aspects; the rest were in color and on clinical aspects. Finally, the book is enriched with three photographs, which according to the copies can be colored by hand or not, in order to highlight the cutaneous lesions. The photographs were

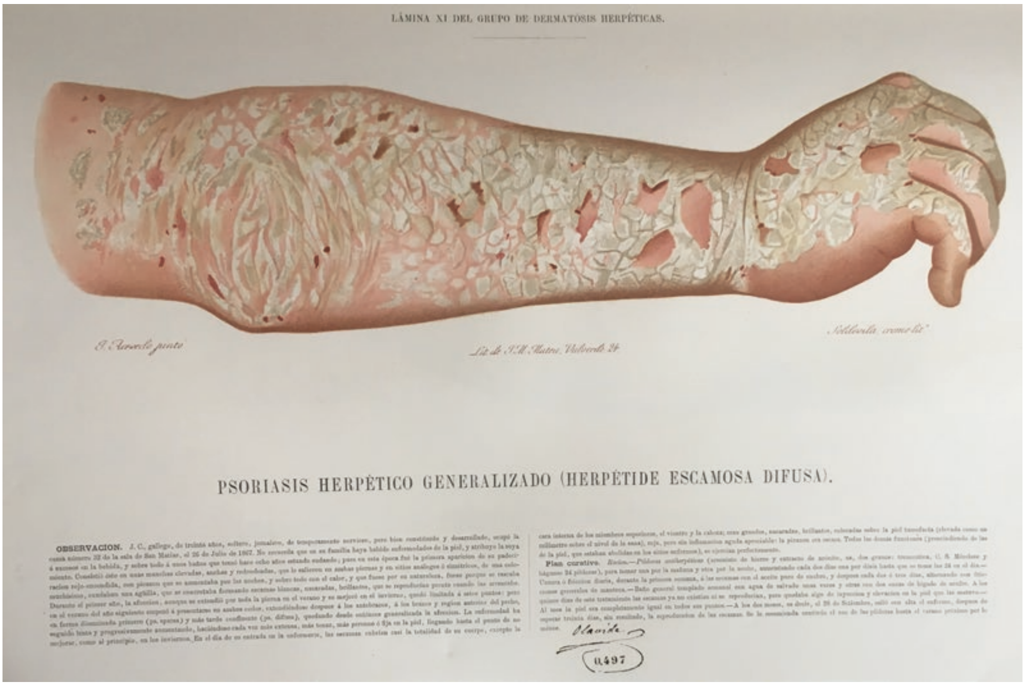

Fig. 2.19 Generalized herpeticum psoriasis (diffuse squamous herpetide). Many of Olavide's illustrations are very detailed (Private collection Dr. Xavier Sierra)

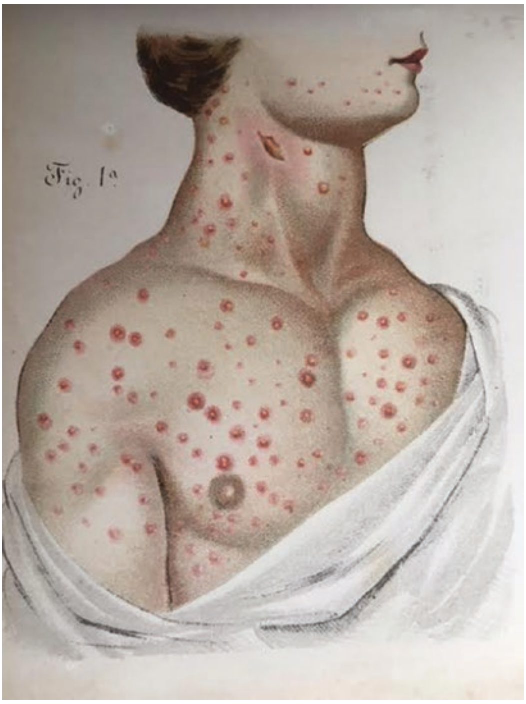

Fig. 2.20 The images in Giné y Partagás book were simpler than the ones found in Olavides's book, but the book was more affordable. (Private collection Dr. Xavier Sierra)

albumin copies of 7 × 10.5 cm and glued by hand, directly on the book page, like a sticker album and is the first testimony of photographs in a treatise on dermatology in Spain [27].

Due to the difficulties in having access to scientific photography, some texts were still published without any photographs, among which we can highlight the work of venereal diseases of Giné himself [28], published 3 years later, or that of the Andalusian Ramón de la Sota and Lastra. However, with Giné's dermatology book, the photographic period in medical texts was inaugurated (Fig. 2.21). Photography was progressively implanted in clinical dermatology as well as in the laboratory. At the turn of the century, photography ended up undoing the other ways of representing skin diseases.

Fig. 2.21 Giné y Partagás was the first author to incorporate photographs in a dermatology book in Spain (From the book *Tratado Clínico Iconográfico de Dermatología Quirúrgica* by Juan Giné y Partagas) (Private collection Dr. Xavier Sierra)

2.6 The "Moulages" or Wax Molds

From the late eighteenth century to the first third of the twentieth century—in addition to lithographs, drawings, and watercolors—*moulages* or wax molds were an important way of representing skin diseases [29]. The wax figures allowed reproducing the various pathological alterations of the skin in three dimensions, in color, and with amazing verisimilitude. They became a fairly common resource in the large teaching centers of the time, which used to house molds museums.

The art of the wax mold has its aforegoings back in the Middle Ages, in the votive offerings that were presented in sanctuaries as thanksgiving. They were used as scientific didactic material for the first time in the 17th century after the development of anatomy. Gaetano Giulio Zumbo (1656–1701), an Italian wax artist later called "the anatomist," and Guillelmo Desnoues (1650–1735), a French surgeon and first surgeon of the Genovese Republic, were pioneers of anatomical ceroplasty. In the 18th century, this technique was perfected, especially in Italy (Bologna, Florence) and later in Vienna and Paris [30].

The first molds of skin diseases were made by Franz Heinrich Martens (1778–1805), a professor at the University of Jena, who received the support from German writer Johann Wolfgang von Goethe (1749–1832) [31] who, during a trip to Florence, was able to visit an important anatomy museum.

Shortly after, another wax sculptor named Joseph Towne (1806–1879) [32, 33] made a large number of anatomical figures in London. Under Thomas Addison's (1793–1860) influence, he modeled many pieces of dermatological pathology. Most wax sculptors were not doctors, but specialized craftsmen, although they had to work closely with dermatologists to learn the most relevant aspects of skin lesions. Some of them did have the double medical-artistic training, such as Anton Elfinger, an Austrian physician and illustrator, whom we have already mentioned as being a great dermatologist and watercolorist of the Viennese school and who also made *moulages*, and Angelo Bellini, doctor and wax sculptor of the dermatology department in Milano [34].

But undoubtedly, the most famous of all dermatological wax modelers was Jules Baretta (1833–1923). Some dermatologists, such as Charles Laillier (1822–1893), had tried to perfect the reproduction of skin diseases by commissioning some cardboard-stone sculptures for better seeing the relief of lesions. The result was not bad, but the sculptures, with the passage of time, blackened and lost their color. Trying to improve the technique, Laillier found Baretta, who had an establishment of colored wax molds with a decorative purpose (fruits and flowers). Laillier, interested in the perfection of the molds of Baretta, proposed to him to make the molds in the hospital. Baretta left his store and settled in Saint-Louis in 1863 and took over the technique of making moldings that would make him famous among dermatologists around the world (Fig. 2.22). He made his first *moulage* in 1867 [35], and since then he was the only artisan who worked at Saint-Louis. In addition to the Saint-Louis Hospital's moulages, Baretta made pieces that contributed to enrich the wax collections of Lyon, London, Boston, and Philadelphia. At his death, Baretta was succeeded by other artisans who continued his work: Font (1914), Niclet (1920–1925), Couvreur (1925–1928), and Littré (1928–1965). When he died, in 1923, he had made more than 3500 pieces.

Fig. 2.22 Moulage of Secondary Syphilis from the Museum of Saint-Louis Hospital of Paris (© F.Marin, P.Simon /Musée des moulages, Hôpital Saint-Louis, AP-HP)

In 1866, French dermatologist Marie-Guillaume-Alphonse Devergie (1798–1879) had the idea of creating a collection of pathological conditions at the Saint-Louis Hospital, where moulages, watercolors, and drawings [36] were put together. The French neurologist Désiré-Magloire Bourneville (1840–1909)—known for describing the "*Bourneville syndrome*," today's tuberous sclerosis—worked at Saint-Louis and became a member of the French Parliament from where he contributed to the full consolidation of the museum. It was officially inaugurated in 1889, during the celebration of the first International Congress of Dermatology, which coincided with the Universal Exhibition on the occasion of the centenary of the French Revolution [37]. A large number of dermatologists from some 30 countries could then admire the extraordinary exhibition of molds, which were arranged according to the alphabetical order of diagnoses in 162 showcases, in the style of natural history museums, along a room of more than 400 m^2 (Fig. 2.23). With this alphabetical disposition, the Saint-Louis dermatologists sought two purposes: on the one hand, to facilitate access to the museum for students, even the most inexperienced in dermatology, and on the other hand, to show their rejection of the current classifications, which had generated conflict in more than one occasion.

The Saint-Louis exhibition impressed the congress attendees. Among them, Moritz Kaposi (1837–1902), head of the Vienna school, conceived the idea of creating similar museum in their hometowns. Other similar museums exist in various countries, especially in Germany [38–40], Austria, Switzerland [41], Italy, the United States [42], Japan [43], and Greece, which are generally related with teaching and are found in connection to centers that originated great dermatological schools. Currently, more than 60 universities retain some tens of thousands of dermatological moulages [44]. Even some faculties like Zürich [45], Dresden [46], or Riga are still today, in the middle of the photography era, producing new molds for teaching purposes as well as restoring dermatological wax molds like those of the city of Rosario (Argentina).

In Spain, José Eugenio de Olavide (1836–1901), shortly after arriving at the San Juan de Dios Hospital in Madrid, felt the need to transmit

Fig. 2.23 View of the Musée des moulages of the Hôpital Saint-Louis of Paris (©Musée des moulages, Hôpital Saint-Louis, AP-HP)

his teachings to a group of collaborators. For this, Olavide founded a museum of wax molds, in the image of Saint Louis's. He had the support of a magnificent sculptor, Enrique Zofío. One of Olavide's collaborators, Dr. Fernando Castelo, believed that Zofío made more realistic moldings than Baretta himself! [47] (Fig. 2.24). In 1882, the museum was solemnly inaugurated [48]. It came to have more than 1000 pieces, which made it appear among the most important in the world, after the Paris (4800 moulages), Vienna (3000), and Zurich (2000) collections. Some of the figures in the museum represent real-life, full-body patients with great realism.

Enrique Zofío, José Barta, and Rafael López Álvarez stand out among the artists who made the molds. The figures were arranged in glass cases similar to large glass cupboards (Fig. 2.25). An etiological classification had been attempted, but most diseases of the time were of unknown cause, so they ended up being grouped by morphology or clinical similarities. Each piece was usually accompanied by a clinical history or a short legend. In a footnote or on the reverse side indicated the medical consultation to which the patient belonged and from which the mold had been extracted.

Fig. 2.24 *Moulage* of *Cutaneous horn*, from the Olavide Museum, Madrid. (Photography by Sierra, X. with permission Museo Olavide)

Fig. 2.25 Natural size whole body wax mold of a girl with tinea faveum. Figura de cera de tamaño natural representando una niña con tiña fávica generalizada. Olavide Museum, Madrid (Photography by Sierra, X. with permission Museo Olavide)

After the disappearance of the *San Juan de Dios* Hospital (1965), the pieces of the wax museum were stored in wooden boxes and remained for a long time in a warehouse, almost forgotten. Thanks to the work of Dr. Luis Conde and his collaborators, Amaya Maruri and David Aranda, the collection was recovered, restored, and studied properly [49], and the museum has been reopened in the University City of Madrid [50].

2.7 Netter's Legacy

It would be unfair not to mention one of the most important illustrators of the twentieth century: Frank H. Netter (1906–1991). A surgeon and medical illustrator, he trained as an artist and then as a doctor. Soon after finishing medical school at the time of the Great Depression, Netter decided to keep accepting freelance art commissions. After a fortunate misunderstanding where he got paid for a series of illustrations double than he had expected, he retired from medicine and spent the rest of his life as an artist.

His almost 4000 illustrations—included not only dermatology but a renown *Atlas of Human Anatomy*, an anatomy coloring book, and the legendary series of Green Books with pictures of most organ systems—have been fundamental in educating thousands of doctors still today.

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3

History of Veterinary Illustration and Photography

Esther van Praag

Contents

3.1 Introduction

During the fifteenth and early sixteenth century, scholars and physicians manifest little interest in animals and their health. Information on animal diseases and their treatment is scarce. Receipts may be found in books describing techniques of venery with dogs or falcons such as the *The Book of Hunting* by George Turberville (1576). When an animal was sick or needed to be castrated, physicians and surgeons specialized in human medicine were consulted despite the fact that they lacked knowledge about animal anatomy and medicine. As a result, animals were treated from a human perspective, with a poor outcome. In a quest for knowledge about functional morphology, European humanists and artists rediscovered animal and man 2000 years after the scientific studies of the Greek philosopher Aristotle (384–322 BC). They do not merely watch at living beings, but appreciate and notice their natural forms according to the classical traditions of Greek art [1, 2]. Artists start to perform dissections of animal and human bodies in an attempt to understand their dynamics: how they can remain still, maintain a posture, or move. Leonardo da Vinci (1452–1519) was interested more specifically in the study of equilibrium and anatomy based on the muscular and skeletal systems of living beings. His anatomical investigations and understanding of complex systems aimed both art and science and led to important discoveries [3,

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4]. Animal drawings emphasize his concern for details. His methodical approach is characterized by the use of linear markings to illustrate proportions of man or, for instance, horses. Meticulously recorded findings are accompanied by complex drawings, which printing methods of that time were unable to reproduce accurately in scientific treatises. This became possible 150 years later only. The results obtained by da Vinci have served the interests and curiosity of scientists and scholars over the next centuries. Raphael (1483–1520) and Michelangelo (1475–1564) also performed dissections of the human body in order to understand anatomy and statics. Their approach is artistic rather than scientific and centered on the human being. Their studies aim to represent accurately positions of corpses in their paintings. Raphael used lines to define the body: a series of horizontal lines and one vertical line. His anatomical drawings did, however, remain unnoticed by scholars and physicians interested in medical anatomy, on the contrary to those of Leonardo da Vinci.

3.2 Macroscopic Observations

During the sixteenth century, animal illustrations are limited to studies by artists and to woodblock prints illustrating folk medicine traditions. The printing technology is simple and outlines the shape of an animal. Details are limited to the strict necessity. As the demand for books increased, the technology of woodcut printing improved. The degree of details became more sophisticated, adding refinement and allowing subtle pattern textures and tones. Colors were added by hand. Treatises such as *Dei discorsi nelli sei libri di Pedacio Dioscoride Anazarbeo della Materia Medicinale* by the Italian physician Pietro A. Mattioli (1501–1578) summarize the knowledge of plant and animal remedies [5]. It is based on the work of the physician, pharmacologist, and botanist Pedanius Dioscorides (40–90 AD) and knowledge gained by Mattioli while exploring the remote Alpine Trentino region, new imported knowledge from the East and from America, as well as archaic beliefs of traditional folk medicine like the use of a hare limb to treat breast infections (mastitis) or the external use of a black hen against typhus [6]. The treatise is illustrated with numerous plant and animal prints (Fig. 3.1). Animal species can easily be recognized, but details characterizing a specific type within a species are absent. This simplicity can be explained by the desire of the author to stick to descriptions as in the original text of Dioscorides and by the limits of printing technology during the sixteenth century. More than 30 editions of Mattioli's work have been published. Successive editions of the book were enriched with Mattioli's comments and new descriptions. This book has, moreover, been translated into Italian, French, German, and Czech.

The Swiss physician Conrad Gesner (1516–1565) compiled the exhaustive *Historia anima-*

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contrepoiſon beuë auec du vinaigre, ſur tout contre le laict caillé en l'eſtomac, & les morſures des viperes. Si on ſe frotte du ſang tout chaud du lieure, il nettoye les taches du viſage, lentilles, & vitiligines.

LIEVRE MARIN.

LE lieure marin a eſté ainſi premierement nommé, ſelon que pluſieurs ont eſcrit, parce qu'il repreſente la forme d'vn lieure de terre. Pline en a ainſi eſcrit au li. 9. cha. 45. Le lieure de la mer Indique eſt venimeux au toucher, il cauſe vomiſſement & deuoyement d'eſtomac. En noſtre mer ce n'eſt qu'vne piece de chair ſans forme, ſemblable au lieure ſeulement de la couleur. Celuy des Indes eſt plus grand que le noſtre, de poil plus dur, lequel on ne prend iamais vif. Par là on peut iuger que Dioſc. parle pluſtoſt du lieure de nos mers, que de celui de la mer des Indes, parce qu'il le fait ſemblable à vn petit calamar. Selon Elian le lieure marin reſemble à vn eſcargot tiré hors de la coquille, auquel retire fort celuy duquel nous auõs

LIEVRE MARIN II.

LEPRE TERRESTRE.

Fig. 3.1 Animal taxonomy is absent during the sixteenth century. Sharing a name part the sea hare mollusk is classified with the terrestrial hare mammalian (Courtesy: Private collection VP)

Fig. 3.2 Woodcuts with limited details are found in the work of Conrad Gesner (Courtesy: Private collection VP)

lium quadrupedum [7, 8]. Animal woodcuts illustrated “existing” animals (Fig. 3.2). They were classified alphabetically. The treatise contains descriptions obtained from reliable sources, “borrowed” illustrations from artists such as Albrecht Dürer (1471–1528) or Lucas Schan (1526–1558), as well as legendary or mystical animals like the unicorn. Diseased animals are also present. A famous one is the horned rabbit, based on folktales and studies by naturalists who observed horned hares and gave it the Latin name *Lepus cornutus*. This was a misconception. There are no known accounts of hares and rabbits afflicted with hornlike protrusions around their head in Europe prior to the sixteenth century [9]. The first observations and records of horned hares in Europe happen at the same time as the increase in trade with the North American continent. It is speculated that travelers could have been passive carriers of the Shope papilloma virus causing papilloma tumors, from North America, where it struck cottontails, to Europe. The methodological and quantitative approach of Gesner bears similarities with that of the Italian physician Ulisse Aldrovandi (1522–1605) [10–12]. They both recorded information on animals available at their time, but lacked of critical thinking skills. As a consequence, legendary or mystical animals have been included in their encyclopedic work. Zoology was born! It separated into animal science and veterinary medicine only centuries later.

In 1657, the Polish physician and naturalist Joannes Jonstonus (John Johnston, 1603–1675) published *Historiae Naturalis de Quadrupedibus* (A description of the nature of four-footed beasts) in Latin. His zoological encyclopedia is based on works of his predecessors, including Conrad Gesner. Many illustrations are from the Swiss-born engraver Matthäus Merian, fully acquainted with the new technique of the copperplate engraving. Detailed illustrations of animals became possible. Mythological animals were included in the book: a variety of unicorns, horned hares (Fig. 3.3), a mermaid, a griffin, a dragon, a phoenix, or a harpy with the head of a woman and the body of a bird. A copy of the 1663 edition was given to the military commander ruling Japan (Shogun). It was used by Japanese scholars as a source of knowledge about western animals for the next 100 years [13].

The zoological encyclopedia of John Johnston is considered as the last of this kind published in Europe. The anthropocentric approach and collection of zoological images was less valued. Instead, anatomy and schematic illustrations of animal anatomy became increasingly the center of interest of scholars and anatomists. This was the consequence of an unstable political and religious situation all over Europe, caused by numerous conflicts and wars. Exodus of rural populations and their livestock lead to famine. Epizootic diseases decimated livestock and herds [14]. Cavalry units had a shortage of saddle and draft horses. At last, scholars found it “worthy of consideration” to study animals and understand their anatomy, illnesses, and suffering. Detailed woodcuts and, later, copperplate engravings about animals and their anatomy were published. These studies were limited to the methodical and thorough examination of living beings without the use of enlarging tools. A perilous exercise when done carelessly; wrong deductions that lead to wrong conclusions and a compromise in diagnosis and treatment.

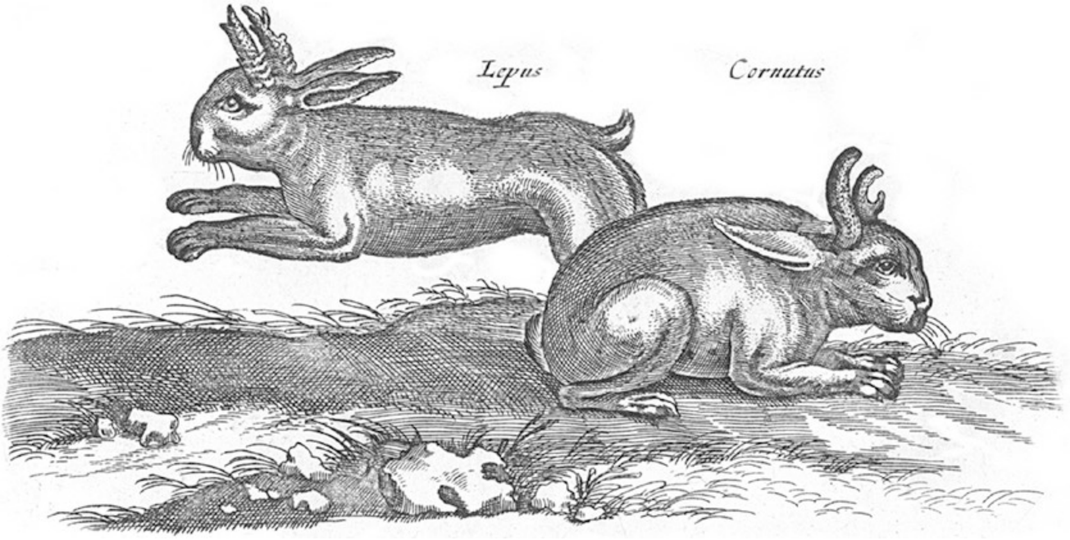

Fig. 3.3 Detailed copper engraving of the mythical horned rabbit *Lepus cornutus*, as found in the zoological encyclopedia by Joannes Jonstonus (1657) (Courtesy: Private collection VP)

3.3 Comparative Study of Body Structures

So far, artists and anatomists used the Greek concept based on animal studies by Aristotle. From then on, the visual formulas established by the Flemish physician and anatomist Andries Wytinck van Wesel (1514–1564) were favored. The latter is better known as Andreas Vesalius, author of *De humani corporis fabrica* (On the Fabric of the Human Body) published between 1539 and 1542 in Basle (Switzerland). He revolutionized the practice of medicine and the study of biology and anatomy to this day [15].

The approach by Vesalius to human anatomy is reflected in the illustrations of a bird and man skeleton in a monograph on the natural history of birds *L'histoire de la natvre des oyseavx, avec levrs descriptions, & naÏfs portraicts* (Fig. 3.4) published in 1555 by the French naturalist and diplomat Pierre Belon (1517–1564). At the end of the sixteenth century, the Italian equestrian Carlo Ruini (1530–1598) was fascinated by natural sciences, taught to him by private tutors [4, 16]. In 1598, he published *Anatomia del cavallo, infermità, et suoi rimedii* (Anatomy of the horse, sickness and natural remedies) in Bologna (Italy). Woodcuts of horse anatomy were depicted like those of man, in order to compare similarities and differences. Although Ruini was not associated with any academic institution, his textbook on horse anatomy was republished numerous times over the next centuries, plagiarized at times, and used in the first veterinary schools during the eighteenth century.

The association of animal and man anatomy settles the basis for "comparative anatomy," a science that developed only 200 years later. It is used by anatomists in the beginning of the seventeenth century to study specific human and animal organs. The Italian surgeon Giulio Casserio (ca. 1552–1616) and English physician William Harvey (1578–1657) compared, respectively, the laryngeal and auditory apparatus and the anatomy of the cardiovascular system of man and animals [17, 18]. At the turn of the century, the Italian anatomist Girolamo Fabrici (1533–1619) compiled his findings in embryology in *De formato foetu* (The Formed Fetus) [19–21]. Part of his discoveries about semen of man and animals was never been published and are considered lost. His comparative studies with birds and animals influenced embryology scholars up to today.

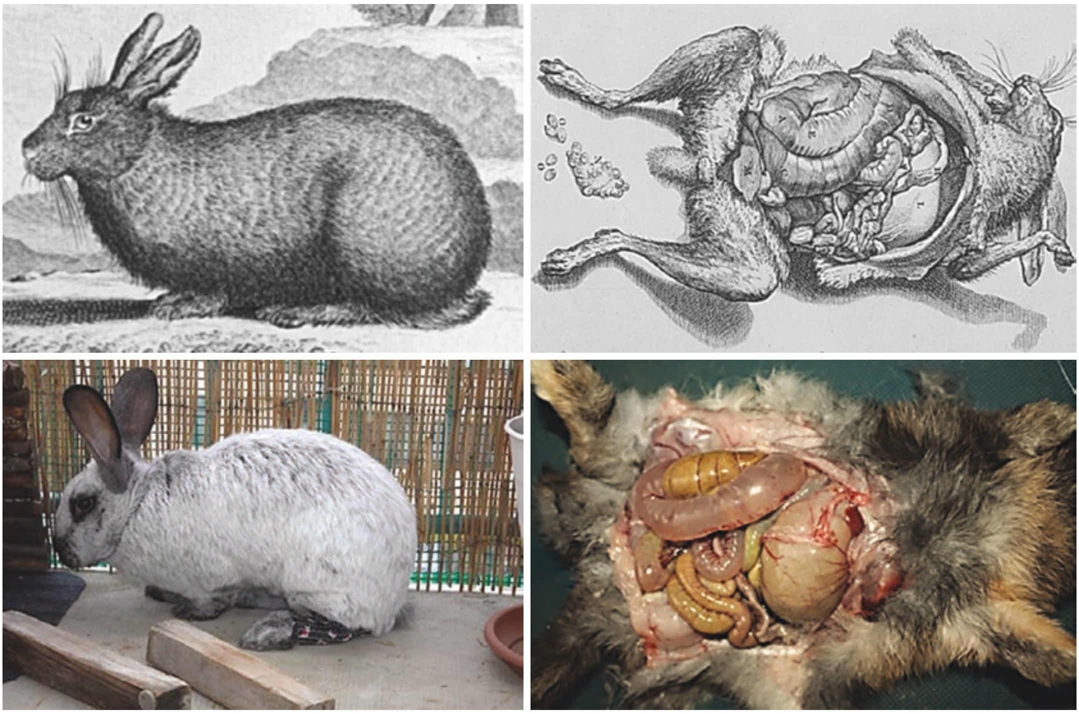

Fig. 3.4 The Age of Enlightenment is also reflected as scientific honesty. Engravings by Buffon can be compared with photographs taken in the twenty-first century (Courtesy: Private collection VP, Esther van Praag, Michel Gruaz)

3.4 From Macroscopy to Microscopy During the Seventeenth Century

A meticulous analysis of tissue samples, body fluids, or dust was difficult during the sixteenth century. Enlarging glasses existed, but their magnifying power was limited. The invention of the compound microscope represented, therefore, a major advance for the medical and animal sciences.

The seventeenth century represents the Golden Age of science and technology in the Republic of the Seven United Provinces of the Netherlands. In 1595 already, the young Zacharias Janssen (1580–1638) started to experiment with the alignment of optical lenses in the top and at the bottom of a hollow cylinder in the workshop of his father, the Dutch spectacle-maker Hans Jansen. To his surprise, the rudimentary instrument was able to magnify objects, ranging from a three times magnification to nine times when fully extended. This instrument was a curiosity rather than used for science. Almost 70 years later, another Dutch scientist and trader, Antonie van Leeuwenhoek (1632–1723), develops a polishing technique that permitted to obtain lenses of superior quality. The "modern" microscope was born that was able to magnify up to 270 times [22–26]. A novelty since most instruments available in his time had an enlarging power of "only" 50 times. Antonie van Leeuwenhoek was able to build a microscope for each new studied specimen, an estimated of 500 instruments. He is, thus, a pioneer in the use of a microscope to study life in water and blood, blood components, sperm cells, bacteria, yeast, and creatures living in dust [27–29]. He documented his findings, launched the concept of a microbial universe, and shared them with the newly created Royal Society of London and the Paris Royal Academy. Artists were commissioned to illustrate his findings. Printing limitations had a negative impact on the quality of the published illustrations of van

Leeuwenhoek, as compared to the refinement seen in the original crayon drawings. Around that time, the Dutch physician and biologist Jan Swammerdam (1637–1680) became the first specialist in microscopy research. He discovered red blood cells too and extends his studies to microscopic studies of insects.

The English scientist Robert Hooke (1635–1703) built his own microscope and confirmed the discoveries of Antonie van Leeuwenhoek. He published them, as well as his own amazing discoveries on small insects and plant cells in the richly illustrated *Micrographia* (1665). His numerous discoveries were a great tribute to microscopy [22, 30].

The use of compound microscopes has had a major impact on the identification and characterization of small organisms and microorganisms and their suspected implication in diseases. Microscopes and magnified images contributed to the advancement of microbiology. Yet, the expertise and know-how gained during the seventeenth century barely evolved over the next 200 years. It was in 1850 when the engineer Carl Zeiss was approached by the botanist Matthias J. Schleiden with the request to build a simple microscope with lenses of improved quality to be used so that the theory of cells can be confirmed [31, 32].

3.5 The "Age of Enlightenment" During the Eighteenth Century

The eighteenth century is referred to as the Age of Enlightenment and represents a turning point in human knowledge [33, 34]. Academic knowledge reaches out of the university walls. Thoughts and concepts gained over the last 150 years are promoted. Philosophers discoursed about the premises of a democratic society versus power embodied by one monarch. Economists debated about new commercial ideas that laid the basis for modern capitalism. Democratization of scientific knowledge was widely encouraged. Scientific academies and societies were created in order to promote research, publish results in journals, and share the gained knowledge to a vast public. Publications in these scientific journals were now protected by a copyright law created in London in 1710. The phenomenon was not restricted to France and England; it spread all over Europe and Russia. New prestigious academies were founded in Berlin, Bologna, St. Petersburg, Uppsala, and Stockholm, and in the Republic of the Seven United Provinces of the Netherlands, based on the English or French model. Scientific societies were created in Turin, Bologna, in several cities in Germany, in Vienna, and in Barcelona. Most societies were later promoted to academies. Freedom and diffusion of notions of Enlightenment reigned in this academia. Patronage and support by royal and noble persons did not influence this freedom.

Enlightenment was also reflected on scientific engravings. Techniques of graphical illustration were fully mastered. Inspirational realist interpretation of past centuries was replaced by representational illustration [35]. Scientific honesty dominated. Consequently, scientists and anatomists studied the dissected animal in front of them and pictured their observations in the best possible realistic way that can be compared with photographs taken nowadays (Fig. 3.4).

The work of naturalist Georges-Louis Leclerc, Comte de Buffon (1707–1788), was representative of the Age of Enlightenment [36–38]. Despite the Church-imposed censure, he believed in the new theories of Isaac Newton (1642–1727) about the creation of Earth and abandoned the belief that the Earth was a few thousand years old and populated by a few thousand animal species only [39]. In its place, he suggested the existence of variability within a species and the inheritance of traits acquired over life to offspring. While he favored the notion of fixity of species, his work resulted in a rudimentary theory of evolution [40–42]. Mostly, Buffon is known for his richly illustrated encyclopedia project, adding knowledge of his time from other experts. In the course of 50 years, Buffon published 36 volumes of *L'Histoire naturelle, générale et particulière, avec la description du Cabinet du Roi* (Natural history, general and particular, with a description of the King's cabinet). Pictures were finely engraved and strikingly humorous at times (Figs. 3.4, 3.5, and 3.6).

Journals and books exposed the extent of scientific breakthroughs and discoveries made during the eighteenth century. New directions were envisioned. One of them was the separation of animal science into biological sciences of animals and veterinary health sciences. The Church, which taught that animal illness was a Divine visitation, was opposed to the understanding of animal epizootics and to veterinary sciences in general [14, 43, 44]. To no avail! Claude

Fig. 3.5 Anatomical illustration of rabbit anatomy as found in the 13th volume of *L'Histoire naturelle, générale et particulière, avec la description du Cabinet du Roi* (1758), by the Comte de Buffon (Courtesy: Private collection VP)

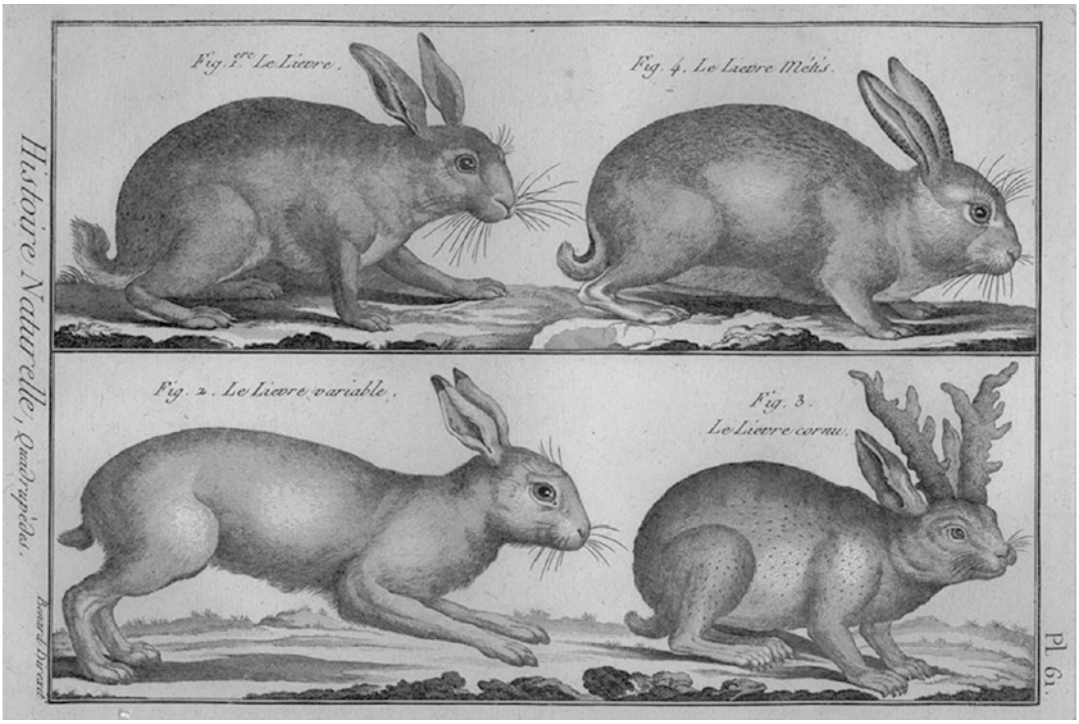

Fig. 3.6 Different known animals within a species, from *L'Histoire naturelle, générale et particulière, avec la description du Cabinet du Roi* (1758), by the Comte de Buffon (Courtesy: Private collection VP)

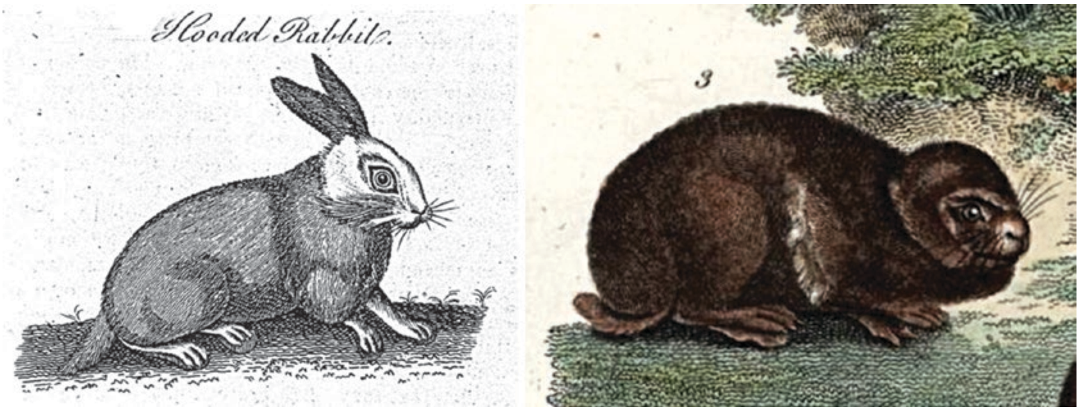

Fig. 3.7 Etchings of the hooded rabbit with palmate feet by Andrew Bell (1726–1809), Scottish engraver and cofounder of the *Encyclopædia Britannica*, and by John Pass (1813), published by George Jones of London (Courtesy: Private collection VP)

Bourgelat (1712–1779) was a strong-minded French equerry and director of the Lyon academy for horsemanship determined to promote horse medicine. After much perseverance, he founded the Royal Veterinary School in Lyon in 1763 with an order by King Louis XV's Royal Council of State [45]. Schools were also created in Alfort in 1766 and in other European cities: Turin (I769), Göttingen, (I771), Copenhagen (I773), and London (1773) [14]. The profession of veterinarian was a turning point in animal husbandry and in the understanding and diagnosis of diseases and injuries in animals and their treatment. Indeed, till the end of the sixteenth century, health care of livestock was mainly in the hand of self-declared "specialists" lacking any medical education and ethical principles, e.g., horsemen, blacksmiths, shepherds, animal breeder, or unlearned medicine men. Their approach to disease was basically the crueler and more hurtful, aimed at the disease, without consideration of the well-being or quality of life of the animal.

The first veterinarians had a link to human medicine: physicians, surgeons, or apothecaries. Veterinary textbooks were expensive, and their content was limited to accurate anatomical illustrations. Etiology of diseases, pathology, and physiology were poorly described, imprecise, erroneous, or simply missing. At the London Veterinary College, the surgeon-farrier and anatomist John Hunter (1728–1793) played a major role to promote the importance of veterinary sciences: 'Whatever may have been done to increase the public stock of knowledge in other departments, the veterinary science hath been hitherto little cultivated in this country' [46]. He dissected animals, experienced, researched, published papers in the *Philosophical Transactions of the Royal Society*, and trained many students. His work was compiled into the *Observation on certain Parts of the Animal Oeconomy* and published in 1792. John Hunter contributed more to veterinary medicine than any animal scientist in the previous 125 years [46].

In spite of the century of scientific honesty, mythical animal species were still present in science books, so was the hooded rabbit, based on a drawing and an account from George Edwards for the British Museum (Fig. 3.7). Thomas Pennant described this peculiar rabbit in *A General History of Quadrupeds* (1793): "with a double skin over the back, into which it can withdraw its head: another under the throat, in which it can place its fore feet: has small holes in the loose skin on the back, to admit light to the eyes: color of the body cinereous: head and ears brown." Its feet are, moreover, palmate!

3.6 The Industrial Revolution and Medical Photography

The discovery of chemical substances such as silver salts altered by the presence of light is quite old. It is first described in 1566 by Georg Fabricius and by the English and German scientists Carl W. Scheele, C. Wedgwood, and Johann H. Schulze during the eighteenth century. While the latter succeeded to reproduce an image on paper impregnated with silver salts, he was unable to stop the process. After a few days, the paper was all black. The French engineer Joseph "Nicéphore" Niépce (1765–1833) was the first to use the UV sensitivity of silver salts successfully in photography, using lavender oil and petroleum to reveal and fix the image (Richet, 1997). Contrast was improved with iodine. He called his technique "heliography." In 1829, he was approached by Louis Daguerre (1787–1851), who aimed to commercialize his invention and improve it. Ten years later, Louis Daguerre presents his improved photographic method: a daguerreotype. It uses the principle of the *camera obscura* ("dark chamber") developed by J.B. Porta during the sixteenth century, fitted with an achromatic lens [47].

The physician Alfred Donné (1801–1878) was quick to realize the merits of photography. He adopted the services of this powerful new ally for his microscopy research: he captured microscopic images of body fluids in 1840 [48]. He used photographs to spice up his lectures but also understood the role of photographs as a comparison tool for microscopic analysis by other clinicians. Thus, A. Donné was a pioneer in the use of photographs for medical and scientific illustrations [48]. His student and, later, physicist Léon Foucault helped develop the first electric microscope with an electric arc as a light source and the "microdaguerreotype" able to enlarge between 20 and 400 times [49]. Donné published an "Atlas" with many photographs. He accompanied them by carefully drawn images, using the photographs as template.

Attempts to publish early medical photographs in anatomy textbooks had, however, limited success in the early years of photography. Indeed, photographs are difficult to interpret due to:

- Spectral sensitivity of early photo materials to blue, violet, and ultraviolet light
- Lack of textural and tonal variations
- Depth of field and distortion due to lens design and lens to subject distance

As a result, photographs had to be retouched or redrawn to make the structures obvious. Processing of photographs into printing was done by hand and was time-consuming. Costs of photographs in books became unaffordable for most authors and publishers.

As photomechanical processes improved and simplified, costs decreased. In 1850, the French photographer Louis D. Blanquart-Evrard developed the technique of albumen silver print and the calotype negative/positive paper process to produce good quality photographs.

Medical photography started to impose itself in publications and books. Over the next decades, physicians started to use photography as a tool to illustrate diseases and visual signs of insanity (mental illness) [50, 51]. It has imposed itself among physicians and in the fields of radiology, pathology, ophthalmology, and motion. For the latter a multi-camera system is used [52, 53].

3.7 Digital Photographs as a Product of Postmodernism

The classical forms of illustrations, such as engravings or paintings, were replaced by photographs in medical and veterinary publications [54, 55]. At the turn of the century, most major centers of medical education started to use photography as a method of documentation, comparison, and study. High-quality medical photographs must depict accurately the body to enable a proper diagnosis and treatment. These specific demands require a full understanding of the principles of photography (exposure, focal length, aperture, shutter speed, depth of field, etc.) as well as control of the camera settings and the environment [55–59]. Photographers working in human medicine came together at Yale University (USA) in 1931 to set standards for medical photography. The Biological Photographic Association and the Journal of Biological Photography were created. It was accompanied by an increased importance of authorship of the photographs and creativity or distinctiveness of the camera work.

Veterinary photography developed after World War II (1939–1945) only. On the contrary to medical photography, the profession of veterinary photographer was considered "half-skilled," and there are no established standards for taking pictures or sharing knowledge through training and apprenticeship. Veterinarians with veterinary clinical careers move into specialist photography in response to a growing demand to document diseases, surgical procedures, or necropsy findings. Individuals develop means of handling their own photographic requirements. Equipment is minimal and self-made. It consists of a camera with a lens, a flashlight and black and white or color films, and a darkroom to develop and fix analogous photographs with specific chemical emulsions. Analogous photography has the disadvantage that manipulation of images is time-consuming and difficult without leaving visible traces (personal communication).

Digitalization represents a significant advancement in veterinary photography (Fig. 3.8) [60]. Film is no more required. The picture elements are a series of pixels, in which each pixel has at least 256 color gradations of red, green, and blue. Histogram, contrast, and focus can be corrected with photo-editing software. Digital photographs can be stored in a computer, viewed and worked on in special programs, and easily reproduced. They also allow an easy and quick distribution among colleagues and specialists for a proper identification of the animal type species as well as a help tool for the analysis and diagnosis of its health problem [61] (personal communication); however, the drawback of this technology is an easy falsification of the digital image without leaving traces and hacking of veterinary data stored in computers or computer networks [62, 63].

Today, there is a new trend to add drawings based on analogous or digital photographs in veterinary publications, as in the early days of medical photography [64]. Scientific drawings based on a picture help to effectively bring attention complex details of a disease, an injury, etc., skin wounds, and a particularity of fur growth or overgrown front teeth, by removing all the "noise." It also creates a personal style for a book (Fig. 3.9).

Nowadays, the veterinarian profession includes generalists as well as specialists like radiologists, surgeons, anesthetists, ophthalmologists, dentists, or veterinarians specialized in specific animals like general pets, exotic animals, horses, etc. Veterinary photography has followed this trend. Many photographers work in central photographic services within a veterinary faculty or in private biomedical communication companies. Some photographers enjoy variety of subjects and situations and photography all topics. Others specialize in a field of medicine: dermatology, ophthalmology, dentistry, surgery, macrophotography, or an animal species.

Fig. 3.8 Veterinary photography has become specialized over the years (Courtesy: Arie van Praag)

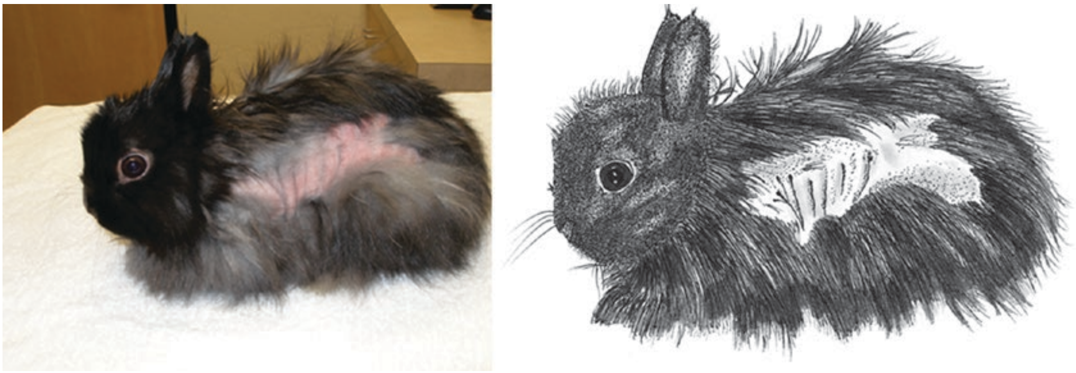

Fig. 3.9 Scientific drawings based on a picture are currently becoming popular again in order to effectively bring attention to complex details of an anomaly, here a hormonal disorder leading to naked flanks in a male rabbit (Courtesy: Kim Chilson, E. van Praag)

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History of Medical Photography

4

Paola Pasquali

Contents

4.1 Introduction

> "Time, space, are thus annihilated, and we identify the resemblance with the reality"
>
> *Walt Whitman* [1]

It all happened 200 years ago; 194, to be exact. This is the time that separates the first know photograph, taken in 1825 by Joseph Nicéphore Niépce and the 2019 picture of the black hole, taken by 29-year-old Katie Bouman (Fig. 4.1).

We have come a long way since Niepce's times. Many photographic processes (Table 4.1) [2] have been developed before we arrived at our present digital era. Almost two centuries of vertiginous advances that make photography still today a unique manner to register the world that surrounds us.

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Fig. 4.1 The first known picture taken by Joseph Nicéphore Niépce, 1825 (Left) and the 2019 picture of the black hole, taken by 29-year-old Katie Bouman and her team (on the right). (Figures under Public Domain, Wikipedia Commons CCBY)

Table 4.1 History of photographic processes

Date	Photographic process
1839–1860	Daguerreotypes
1839–1860	Salted paper prints
1851–1925	Glass plate negatives (general)
1851–1885	Collodion wet plate glass negatives
1878–1925	Gelatin dry plate glass negatives
1889–1951	Nitrate negatives (introduced by Kodak)
1850–1880	Albumen prints
1885–1905	Gelatin and collodion printed-out photographic prints
1880	Black-and-white gelatin developed-out photographic prints
1934	Acetate negatives introduced for sheet film
1935	Chromogenic color film and transparencies (introduced by Kodak; Kodachrome was the first process)
1948	Instant black-and-white process (introduced by Polaroid; sepia first, then black-and-white in 1950)
1960	Polyester film introduced
1963	Instant color print process (introduced by Polaroid; Polacolor was the first process; SX 70 was introduced in 1972 and Polacolor 2 in 1975)
1975	First digital photography
1985	Electrostatic, inkjet, and dye sublimation prints become increasingly used for printing photographic images

Photography has been a *disruptive innovation* right from the beginning. For authors AP Molella and J Beidi [3], photography reframed how we look at the world and ourselves. Although it was invented in Europe, it achieved such a degree of sophistication in America to be referred to as "the American process." Photography stood as the new way to see the world; furthermore, it was believed by many to be the new and objective way to represent reality, away from the subjectivity of art. It created images and copied reality in a manner not found before it. But not only scientists were amazed: artists, technology, and science were joined in amazement to reproduce the world around them, taking concepts one from another. Some artist became inventors; some scientists borrowed conventions from the fine arts and applied them to the new medium. From the etymological point of view, the word "image" should be linked to the root *imitari* [4]. In fact, some used photographs as a control for their painted subjects.

As a substitute of art, it was seen as a labor sparer. The automatism of the process was interpreted as a warranty of impartiality. It was used by scientist to make the invisible visible and also to reproduce nature with extraordinary detail. Machine-regulated image making was a powerful symbol to the goal of abiding objectivity [5]: if it was photographed, it had to be real. By coming from a machine, it had three main characteristics: (1) it could be made to reproduce thousands of copies; (2) it was unbeatable; and (3) it offered images uncontaminated by interpretation [5].

Fig. 4.2 "Spirit photography" by William H Mumler (1860) showing Mary Todd Lincoln with the "ghost" of her husband, Abraham Lincoln. (William H. Mumler, Mary Todd Lincoln, 1872. Courtesy of Allen County Public Library, Fort Wayne, Allen County, Indiana)

Photographs created images in a new way. But it was not any image: it was an accurate representation; that is, it stand to be "the truth"; however, when exploring on the history of disease representation, including medical photography, one can find that regardless of the reproduction media used, each representation had "imbedded cultural and moral understandings of the meaning of illness" [6]. In fact, photography is just another way of representing; it is the vision for a moment captured through the lens [7].

In the field of medicine, this "objectivity" favored a somatic understanding of disease, reducing its complexity to a localized affection visible to the lens of the camera [8], a criticism still made today toward teledermatology.

Even when the first's photographs were seen as the reflection of reality, they were also seen as supernatural. In fact, the first camera well called "the magic box." This aura of verisimilitude was exploited by charlatans like William H. Mumler who in the early 1860s used the double exposure and set a business as "spirit photography." His most famous photography showed Mary Todd Lincoln with the "ghost" of her husband, Abraham Lincoln (Fig. 4.2) [9]. Done the law, done the snare!

This new technology was a democratizer bridging science and art with the lay person: the firsts daguerreotypes represented as a truly democratic form of imaginary [3].

Photography appeared in a period of great changes to society. Science saw the opportunity to go beyond the visible. Physicians either took the pictures themselves or brought their patients to the local portrait photographer [10]. The first medical photographic prints made between 1840 and 1890 could be classified into the following four types: (1) The "grotesque"; (2) classical presentations of medical conditions; (3), war surgical cases; and (4) the mentally ill [10]. In the latter, and just as the Renaissance sought to categorize emotions, doctors used the camera to take photographs that could put emotions and character into evidence. Its use expanded as a means of recording and a source of "creating evidence" in fields like psychiatry, physiology of movement, and the political and police apparatus among others. Generating an image of a human being following "scientific conventions" was and is still being used in a spectrum that spans from medical education, support the theory of eugenics [11] and for surveillance, law enforcement, and control [12]. The power of imaging was soon evidenced.

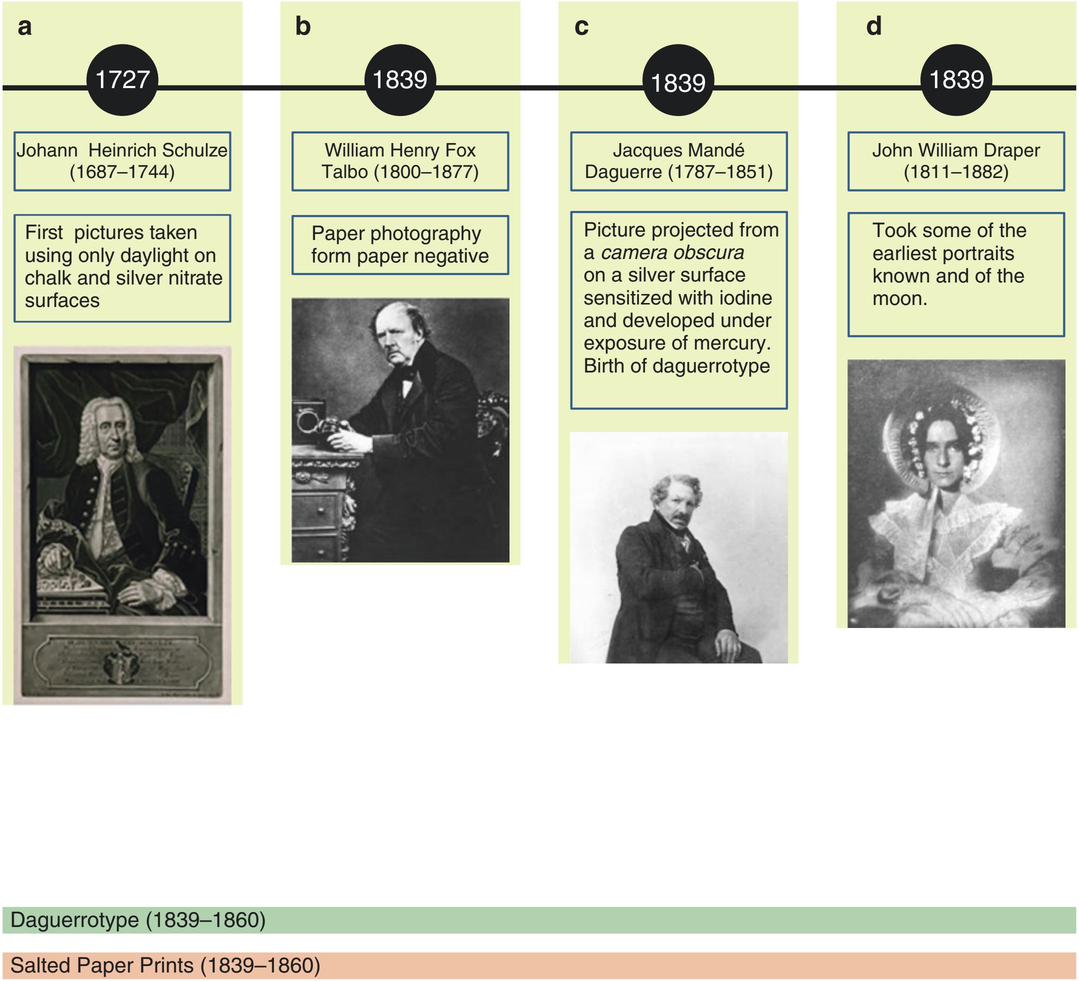


Fig. 4.3 Timetable: From left to right. (**a**) Image of Johann Heinrich Schulze. (Johann Heinrich Schulze. Mezzotint by J. J. Haid after G. Spizel, Wellcome Library Collection, figures under Public Domain CCBY 4.0); (**b**) Picture of William Henry Fox Talbot (1800–1877). (William Henry Fox Talbot, by John Moffat of Edinburgh, May 1864, figure under Public Domain, Wikipedia Commons CCBY). (**c**) Picture of Jacques Mandé Daguerre 1787–1851. (Figure under Public Domain, Gallica Digital Library, CCBY). (**d**) One of the first portraits (1839), taken by John William Draper (1811–1882) of his sister Dorothy Draper. (Dorothy Catherine Draper, earliest surviving photograph of a woman, figure under Public Domain, Wikipedia Commons CCBY)

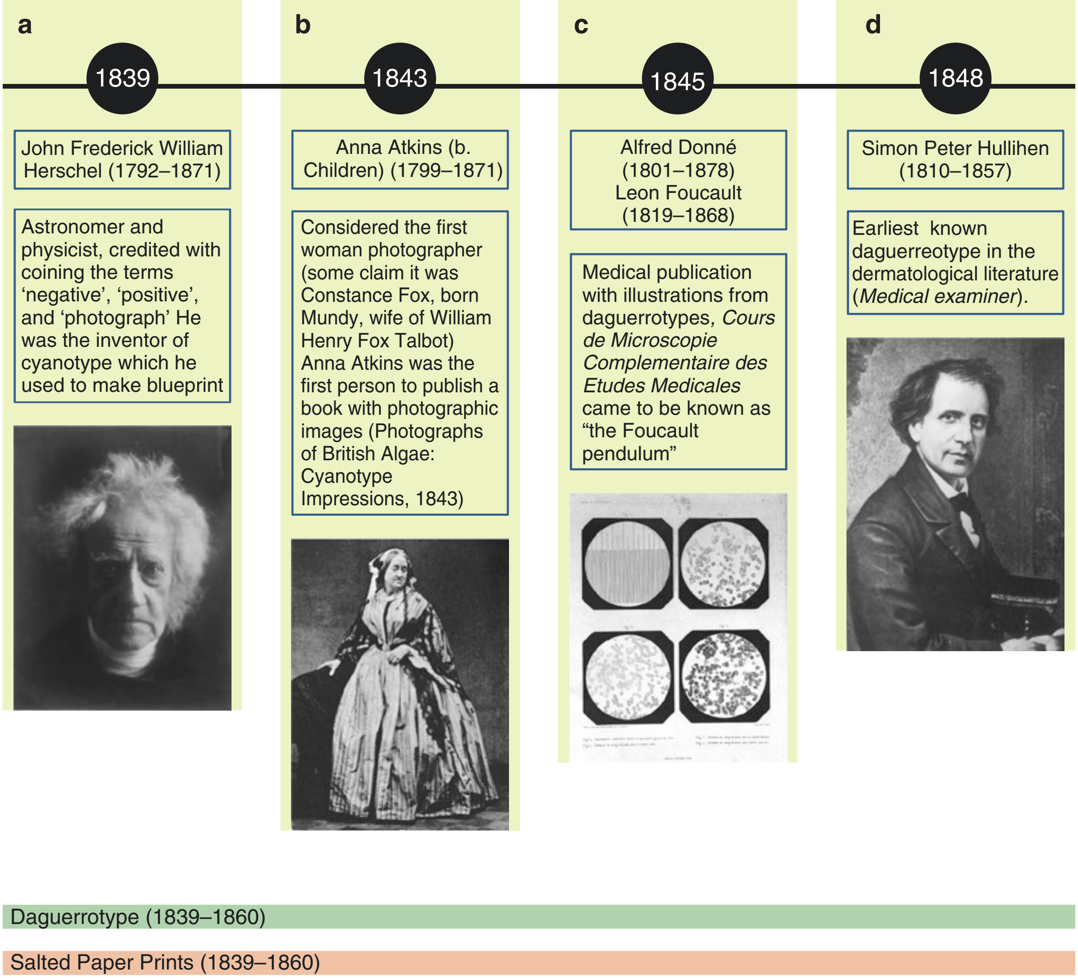
4.2 Time Table

> *The illiterate of the future will not be the man who cannot read the alphabet, but the one who cannot take a photograph.*
>
> Walter Benjamin, 1931 [13]

Medical photography started almost in parallel to general photography: physicians and scientists were among those who first took photographs. The ever-constant stream of new technologies and applications left an imprint on the medical world.

The timeline (Figs. 4.3a, b [14], 4.3c [15], Figs. 4.3; 4.4a, b, c, d; 4.6a, b, c, d; 4.7a, b, c; 4.8a, b, c, d; 4.9a, b, c, d; 4.10; 4.11a, b, c; 4.12a, b, c; and 4.13a, b, c, and d) shows the major development, photographic processes and figures of this exciting period of invention and change [16]. Some highlights were the cyanotype Impressions (1843) by Anna Atkins (Fig. 4.5) or the newly introduced portable camera by Eastman Kodak (1888).

As for skin, its exposed condition made it the leading organ to be systematically photographed.



John Frederick William Herschel (1792–1871)

Astronomer and physicist, credited with coining the terms 'negative', 'positive', and 'photograph' He was the inventor of cyanotype which he used to make blueprint

Anna Atkins (b. Children) (1799–1871)

Considered the first woman photographer (some claim it was Constance Fox, born Mundy, wife of William Henry Fox Talbot) Anna Atkins was the first person to publish a book with photographic images (Photographs of British Algae: Cyanotype Impressions, 1843)

Alfred Donné (1801–1878)
Leon Foucault (1819–1868)

Medical publication with illustrations from daguerrotypes, *Cours de Microscopie Complementaire des Etudes Medicales* came to be known as "the Foucault pendulum"

Simon Peter Hullihen (1810–1857)

Earliest known daguerreotype in the dermatological literature (*Medical examiner*).

Daguerrotype (1839–1860)

Salted Paper Prints (1839–1860)

Fig. 4.4 (**a**) Photograph of John Frederick William Herschel, taken in 1867 by Julia Margaret Cameron. She is considered one of the "giants" of Victorian photography (the other "giants": Lewis Carroll, Lady Clementina Hawarden and Oscar Rejlander). Herschel introduced her to photography in 1839 and shared the results of his early experiments with her. (Figure under Public Domain, Wikipedia Commons CCBY); (**b**) Picture of Anna Atkins, a botanist considered by some the first woman photographer. (Portrait of Anna Atkins, albumen print, 1861, figure under Public Domain, Wikipedia Commons CCBY); (**c**) Image of blood globules from *Cours de Microscopie Complementaire des Etudes Medicales* by Donné and Foucault. (Figure under Public Domain, Wikipedia Commons CCBY). (**d**) Dr. Simon Hullihen (Courtesy of the Wheeling Hospital Collection at the Diocese of Wheeling-Charleston archives)

Fig. 4.5 Cyanotype image from the book British Algae: Cyanotype Impressions, 1843 by Anna Atkins. (Figure under Public Domain, The New York Public Library, Spencer Collection)

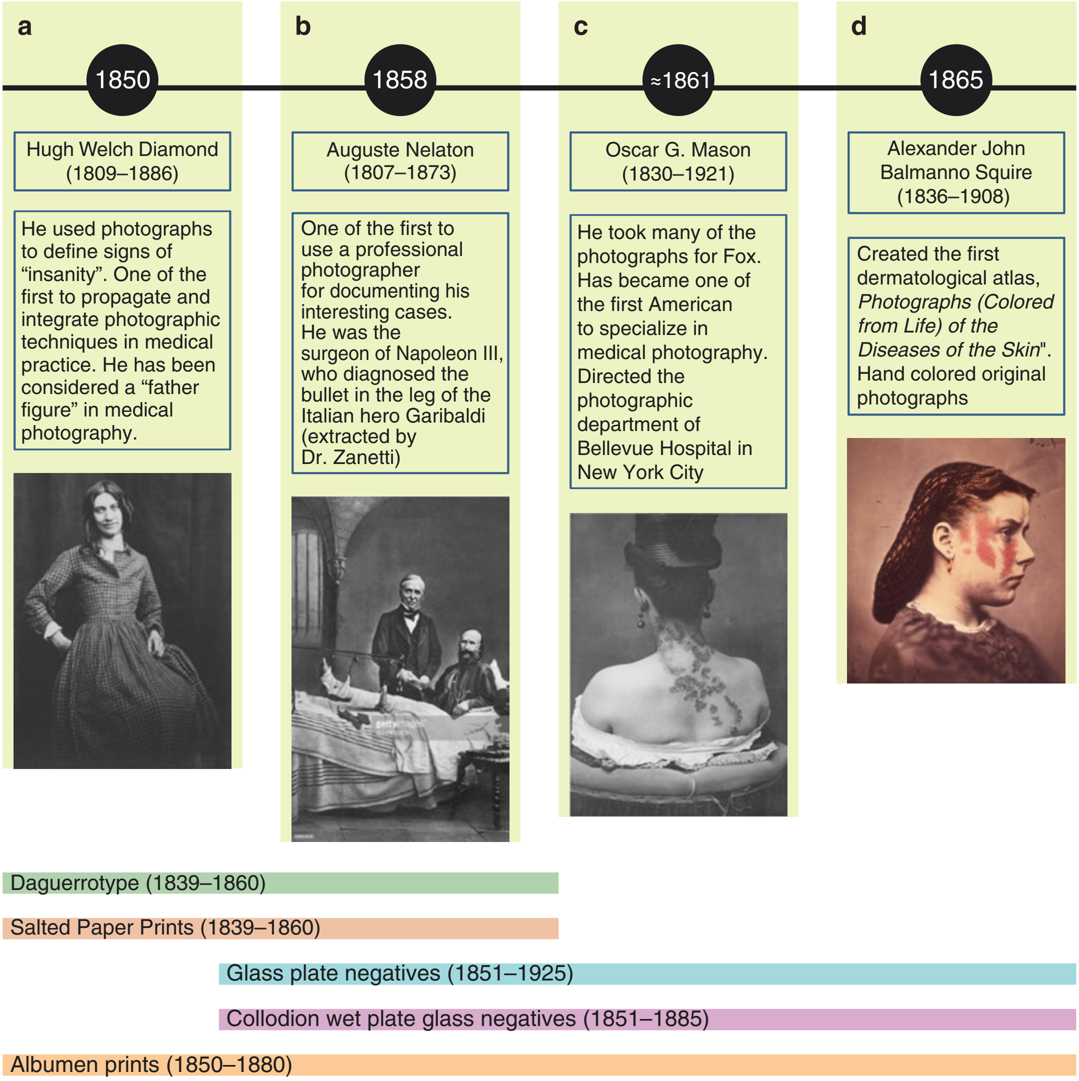


Fig. 4.6 (**a**) Photograph of a patient in a psychiatric ward, by High Welch Diamond (1809–1886) (Figure under Public Domain CCO 1.0 license, The Metropolitan Museum, Gilman Collection, Purchase Ann Tenenbaum and Thomas H. Lee Gift, 2005); (**b**) Auguste Nelaton photograph at the bedside with Giuseppe Garibaldi (Figure under Public Domain, Wikipedia Commons CCBY) (**c**) Photograph taken by Oscar Mason for Fox´s Atlas (Figure under Public Domain, Wikipedia Commons CCBY); (**d**) Photograph from the book “Photographs (Colored from Life) of the Diseases of the Skin” by Alexander Balmanno Squire, John Churchill and Sons, 1865. His book *A Manual of the Diseases of the skin* has been digitalized from the library of Oxford University, figure under Public Domain)

Dermatological photographs were among the first medical images to be reproduced in series for atlases which were used to spread medical knowledge. In this sense, photography can be considered an instrumental part of the emergence of dermatology as a discipline. Over 150 photographs were made public in dermatological photographic atlases published between 1865 and 1900 [10]. The first pictures were black and white and later hand-colored to imitate the naturally occurring condition. Many artistic conventions were borrowed to generate medical portraits. Patients posed as if they were going to be painted for a family portrayal [17]. Gradually, it began a process of standardization, and new pictorial conventions were included to separate medical from popular photographs, a subtle transition from artistic illustration to this new scientific way of imaging.

Fig. 4.7 (**a**) Photograph from the book *Clinique photographique de l'hôpital Saint-Louis* by Louis Philippe Hardy and Pierre Michel Arthur de Montméja (*Clinique photographique de l'hôpital Saint-Louis* / par M. A. Hardy et A. de Montméja, Chamerot et Lauwereyns, Paris 1868, figure under Public Domain) (**b**) Picture of Christian Albrecht Theodor Billroth (Figure under Public Domain, Wikipedia Commons CCBY). (**c**) Picture from the cover of *Revue photographique des hôpitaux de Paris. Bulletin Médical* by Montmeja, Pierre Michel Arthur de; Rengade, P. Jules; Bourneville, Désiré Magloire. (Digital image courtesy of the Getty's Open Content Program)

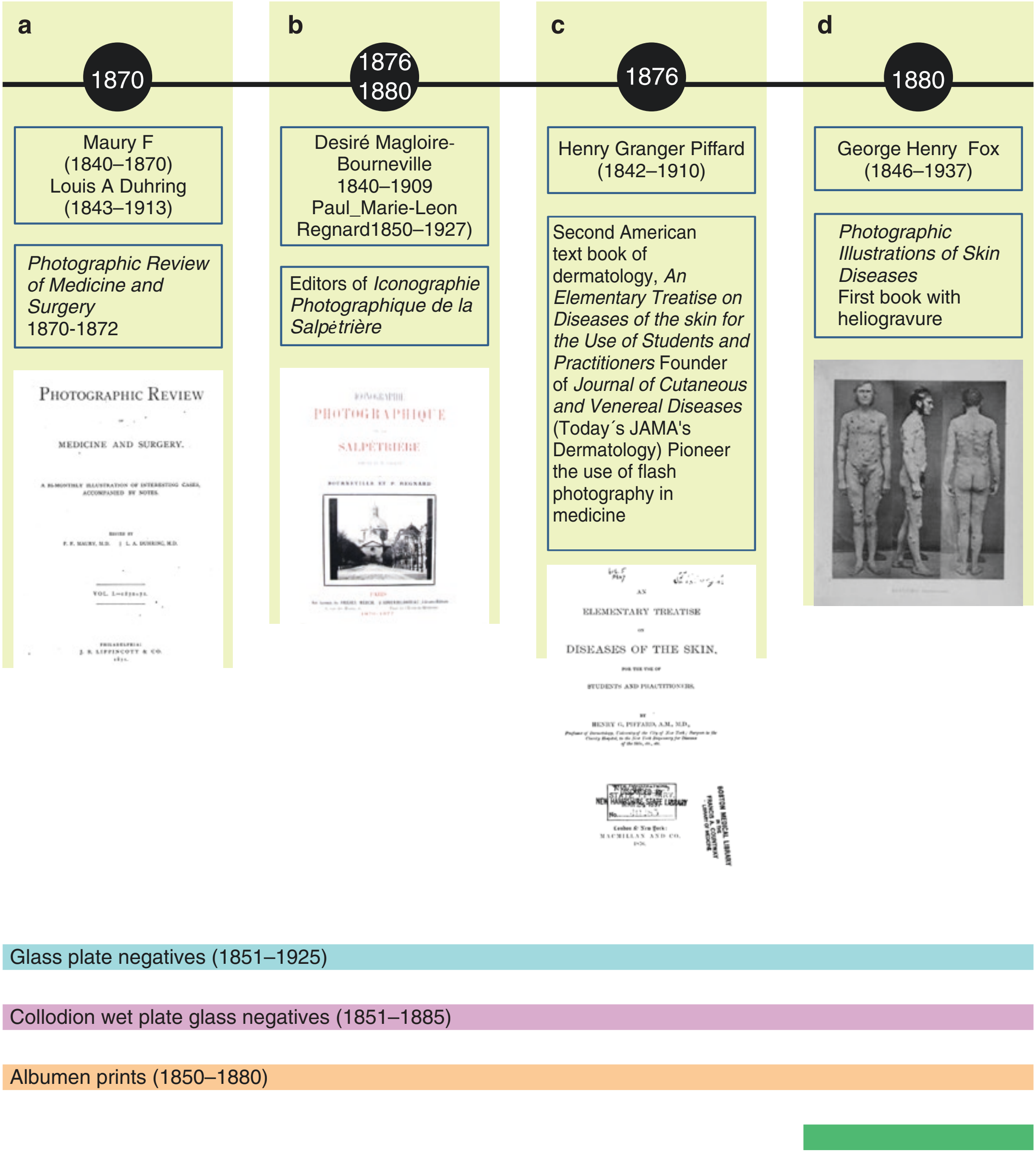


Fig. 4.8 (**a**) First page of *Photographic Review of Medicine and Surgery* by Maury F F and Duhring L A (1870–1871). (From *Photographic review of medicine and surgery*), a bi-monthly illustration of interesting cases, accompanied by notes. Philadelphia: J.B. Lippincott & Co., figure under Public Domain); (**b**) Cover from *Iconographie Photographique de la Salpètrière* edited by Desiré Magloire-Bourneville and Paul_Marie-Leon Regnard (Digitalized from the library of Oxford University, figure under Public Domain). (**c**) First page of *An Elementary Treatise on Diseases of the skin* for the Use of Students and Practitioners by Henry Granger Piffard. (*An elementary treatise on diseases of the skin*, 1842–1910, London, Macmillan and Co., 1876, figure under Public Domain); (**d**) Image from the book *Photographic Atlas of the Diseases of the skin* by the American dermatologist and civil war veteran George Henry Fox. (Emory University Digital Library Publications Program, figure under Public Domain)

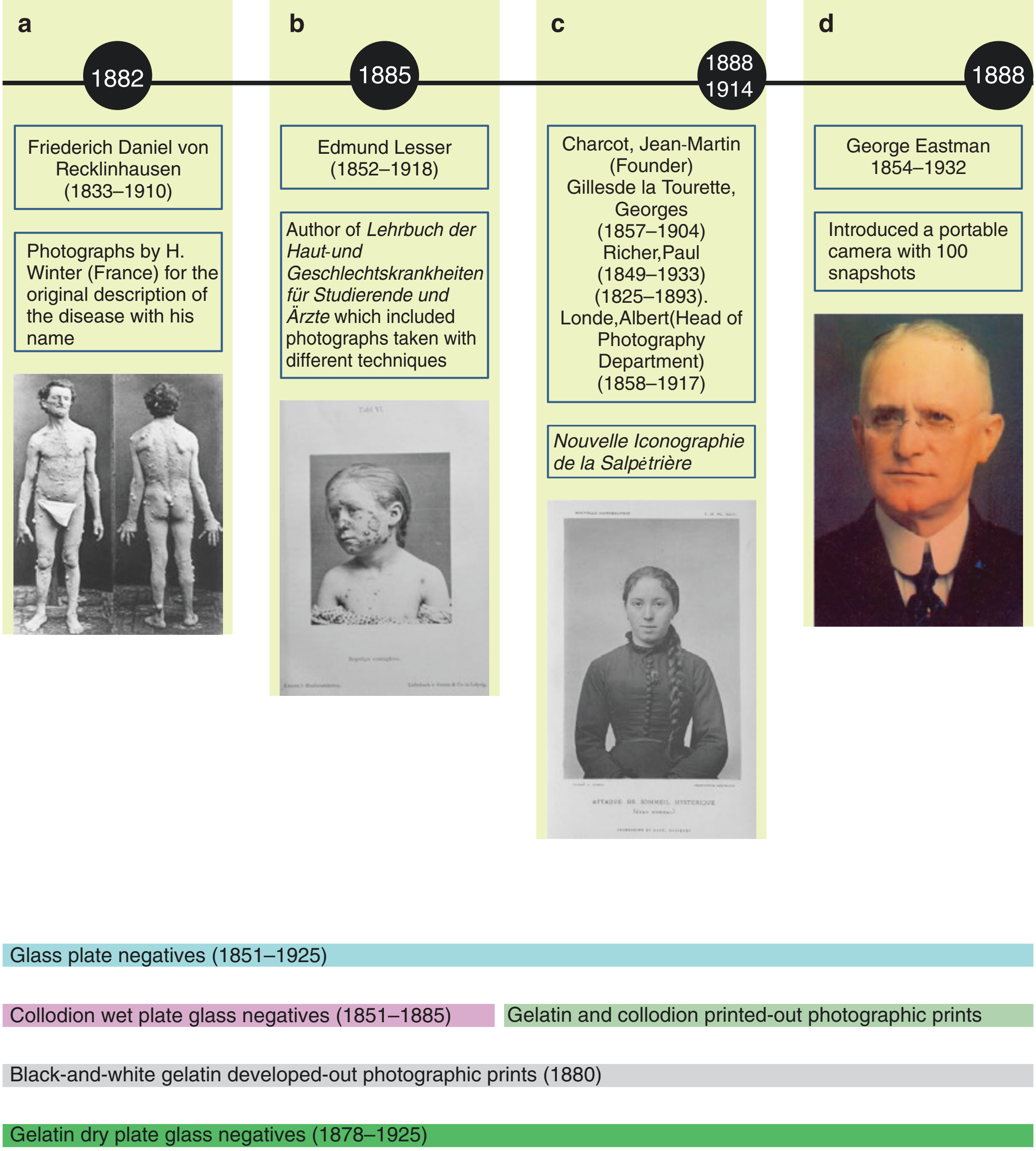


Fig. 4.9 (**a**) Michel Bur was the second case used by Friedrich Daniel von Recklinghausen to describe neurofibromatoses in 1882. The photograph was taken by H. Winter. (Figure under Public Domain, Wikipedia Commons CCBY); (**b**) Image of child with impetigo in Edmund Lesser´s *Lehrbuch der Haut- und Geschlechtskrankheiten für Studierende und Ärzte*. (Wellcome Library Collection, figure under Public Domain CCBY 4.0). (**c**) Hysterical sleep attack (normal state). *Nouvelle iconographie de la Salpêtrîere*. Credit: Wellcome Collection. Attribution 4.0 International (CC BY 4.0); (**d**) George Eastman (1854–1932), fouder of Eastman Kodak Company, inventor of the photographic film (Figure under Public Domain, Wikipedia Commons CCBY)

Fig. 4.10 First advertisement for the newly introduced portable camera from George Eastman: New Kodak Cameras. "You press the button, we do the rest." (Ellis Collection of Kodakiana 1886–1923, David M. Rubenstein Rare Book & Manuscript Library, Duke University, figure under Public Domain)


THE KODAK CAMERA.

"You press the button, -
- - - we do the rest."

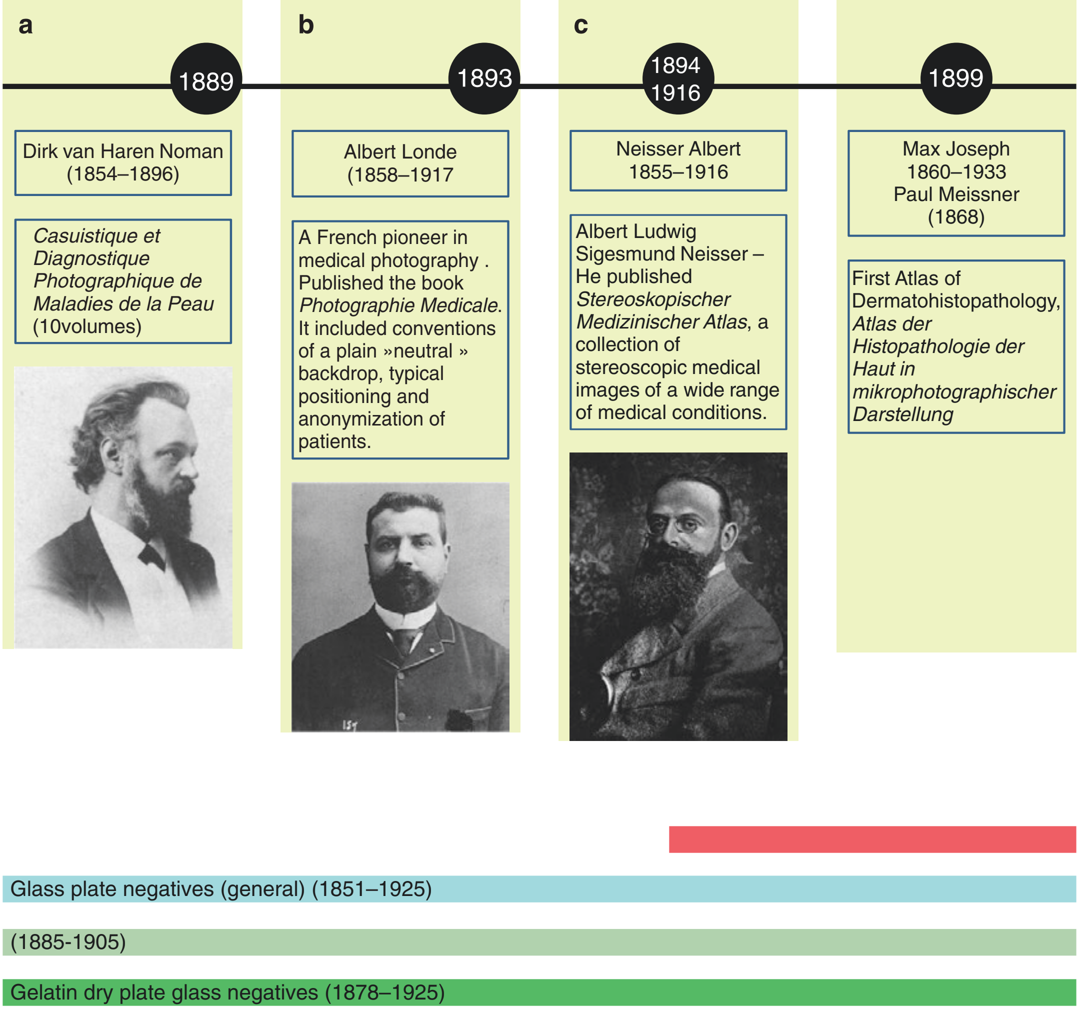
The only camera that anybody can use without instructions. Send for the Primer, free.

The Kodak is for sale by all Photo stock dealers.

The Eastman Dry Plate and Film Co.,

Price $25.00—Loaded for 100 Pictures. ROCHESTER, N. Y.

A full line Eastman's goods always in stock at LOEBER BROS., 111 Nassau Street, New York.



Dirk van Haren Noman
(1854–1896)

Casuistique et Diagnostique Photographique de Maladies de la Peau (10volumes)

Albert Londe
(1858–1917

A French pioneer in medical photography . Published the book *Photographie Medicale.* It included conventions of a plain »neutral » backdrop, typical positioning and anonymization of patients.

Neisser Albert
1855–1916

Albert Ludwig Sigesmund Neisser – He published *Stereoskopischer Medizinischer Atlas*, a collection of stereoscopic medical images of a wide range of medical conditions.

Max Joseph
1860–1933
Paul Meissner
(1868)

First Atlas of Dermatohistopathology, *Atlas der Histopathologie der Haut in mikrophotographischer Darstellung*

Fig. 4.11 (**a**) Dutch dermatologist Dirk van Haren Noman that published *Casuistique et Diagnostique Photographique de Maladies de la Peau* (10 volumes) in 1889. (Figure under Public Domain, Wikipedia Commons CCBY). (**b**) The French pioneer in medical photography, Albert Londe. (Figure under Public Domain). (**c**) Albert Ludwig Sigesmund Neisser. He published *Stereoskopischer Medizinischer Atlas*, a collection of stereoscopic medical images of a wide range of medical conditions. It included a collection of stereoscopic medical images of a wide range of medical conditions. Neisser is better known for discovering the pathogen that causes gonorrhea. (Figure under Public Domain, Wikipedia Commons CCBY)

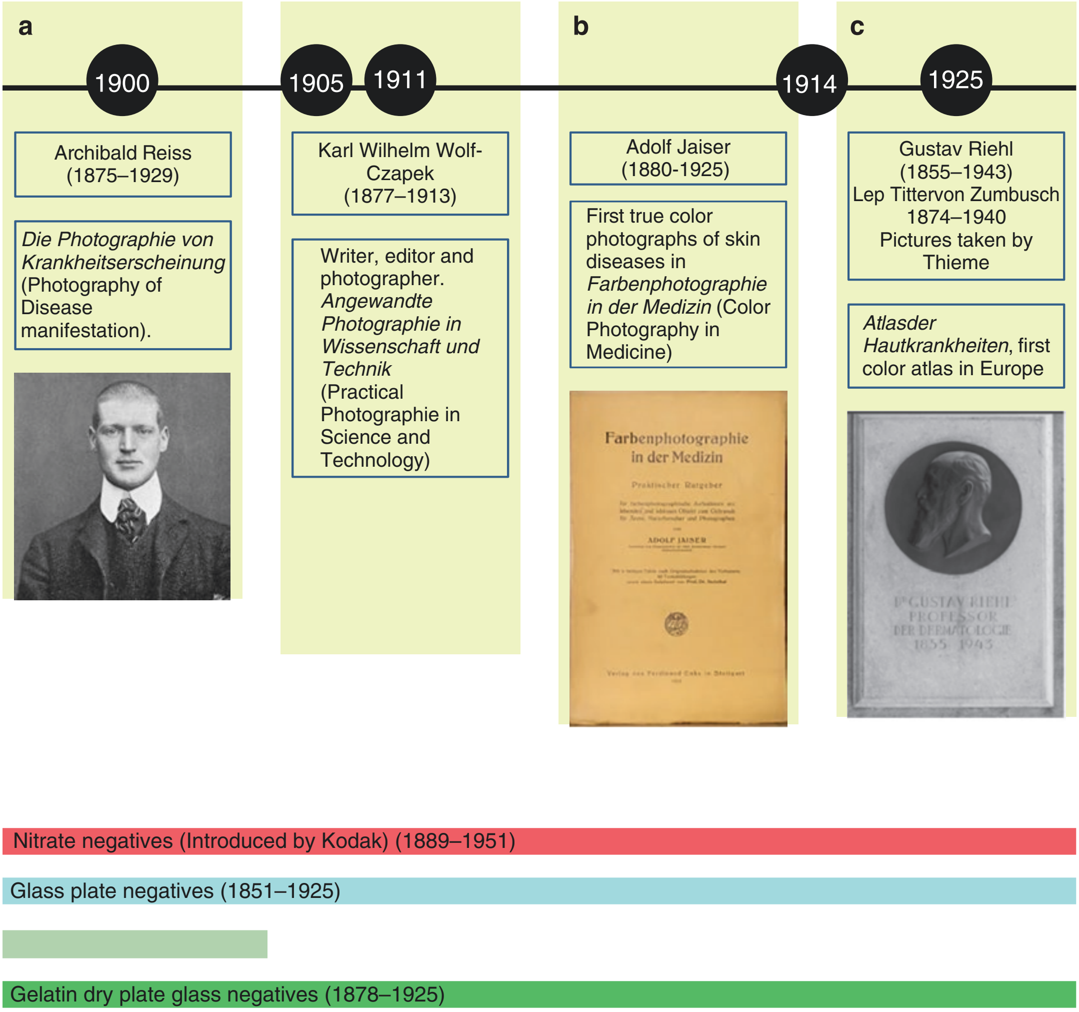


Fig. 4.12 (**a**) Archibald Reiss, better known for founding the first academic forensic science programme and the Institute of Forensic Science (Rodolphe Archibald Reiss, by Bertillon, 1925) (Figure under Public Domain, Wikipedia Commons) CCBY). (**b**) Cover of *Farbenphotographie in der Medizin* by Adolf Jaiser (Figure under Public Domain). (**c**) Austrian dermatologist Gustav Riehl who published in 1925, together with von Zumbusch Lep Titter, the first color atlas in Europe (Gustav Riehl, 1855–1943, Nr. 92 basrelief in bronze, Arkadenhof of the University of Vienna, Photo credits: Hubertl, figure under Public Domain)

Eastman-Kodak (USA) Agfa (Germany) started production of color film, Kodachrome and Agfacolor

Lajos Nékám 1868–1957

Published de proceedings of the Ninth International Congress of Dermatology

First know digital images know. They were sent to Earth by Mariner IV spaceship. They showed the surface of Mars

Willard Boyley George Smith invented the CCD (Charge-Coupled Device), a device which transforms light in to electrical signals. The CCD is the electronic eye of digital cameras, a tool that revolutionized photography by allowing light to be captured electronically rather than on a film.

Motivated by the space race Steven Sasson, an engineer working for Kodak, invented the first digital camera in 1975 and the first practical mega pixel charge-couple device (CCD) image sensor in1986. Sasson's world's first digital camera weighed around 8 pounds (3.6kg) and had a resolution of only 0.01MP; it recorded images on a solid CCD chip

Fig. 4.13 (**a**) First color film by Kodak (1935) and Agfa (1936) (Courtesy of Kodak, Copyright © 2020 Eastman Kodak Company. All Rights Reserved, and Thomas Neumann's Trip to Berlin, 1937, Riksarkivet, National Archives of Norway, figures under public domain). (**b**) Painting of Prof. Lajos Nékám. His most important work is his 3 volume dermatovenereological atlas (1938) which contains 4566 Figures. (Painted by Karoly Karlovszky, courtesy of owner and grand child of Prof. Lajos, Dr. Nékám Kristóf). (**c**) First known image of the surface of Mars (NASA, 1976, figure under Public Domain). (**d**) Steven Sasson and the the first know commercial digital camera (Courtesy of Kodak, Copyright © 2020 Eastman Kodak Company. All Rights Reserved)

4.3 Photographing the Grotesque

> *Tis true my form is something odd,/But blaming me is blaming God;/Could I create myself anew/I would not fail in pleasing you./If I could reach from pole to pole/Or grasp the ocean with a span,/I would be measured by the soul;/The mind's the standard of the man.*
>
> —Poem used by Joseph Merrick to end his letters, adapted from "False Greatness" by Isaac Watts

Grotesque is a word used to define the "repulsive, ugly or distorted." It originated from the Italian word *grotteschi*, which referred to the decorations found in the grottoe (Grotta, Italian for cave) like the ones from the Golden House of Nero and that represent a mix of human and plant forms [18]. Such hybrids gave rise to a name later used to define the freaks.

Humans seem to be drawn to the abject as a mean to reaffirm their own well-being. We seem compelled to stare at the aftermath. The initial "trauma" of staring at the deformed or their images is followed by the reassurance that "it is not me." It gives the opportunity to confront our own fears, while we recognize that image as a subject leaving us in at safe. The large number of images taken of humans with deformities seems to point more to satisfy the appetite for the deviant than a representation of a natural occurring event for academic or documentary purposes.

The history of professional photographs of diseases cannot be disconnected from the representation of monstrous and spectacular cases. These cases were present not only in Atlases but also on personal albums and street exhibitions. Joseph Merrick [19] (Fig. 4.14), the "Elephant man," was just one such case of shared imaging between the medical world and the circus. Contemporary artist and photographer María-María Acha-Kutscher (Lima, 1968) serie *Les Spectaculaires* exposes "freak-women" in all their beauty, re-dignifying them against the violent use of their medical condition for the amusement of others [20] (Fig. 4.15).

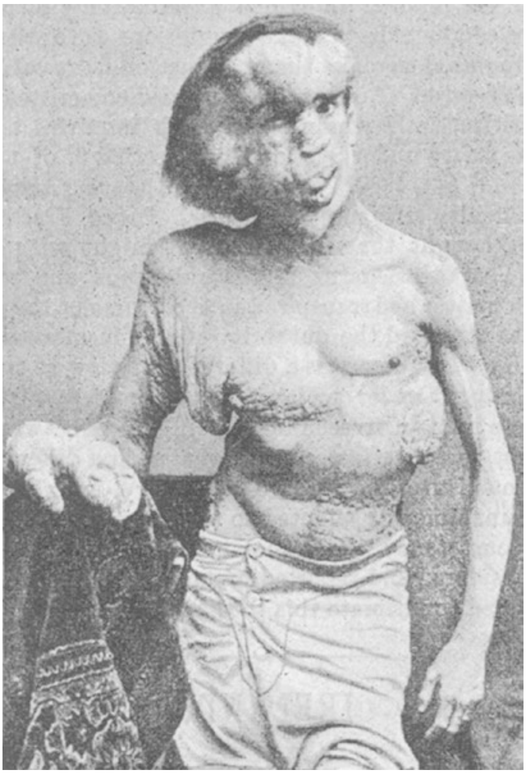


Fig. 4.14 Photograph of Joseph Merrick. (Unknown source, no photographer credited in the British Medical Journal article of 1890, figure under Public domain)

Fig. 4.15 Photographic collage by María-María Acha-Kutscher (Lima, 1968): "Alice E.Doherty" 'Alice La Maravilla'. (From her series *Les Spectaculaires*, 2011) (With permission of María Acha Rodríguez. Artist name: María-María Acha-Kutscher . All rights reserved)

4.4 Photography in the Psychiatric Ward

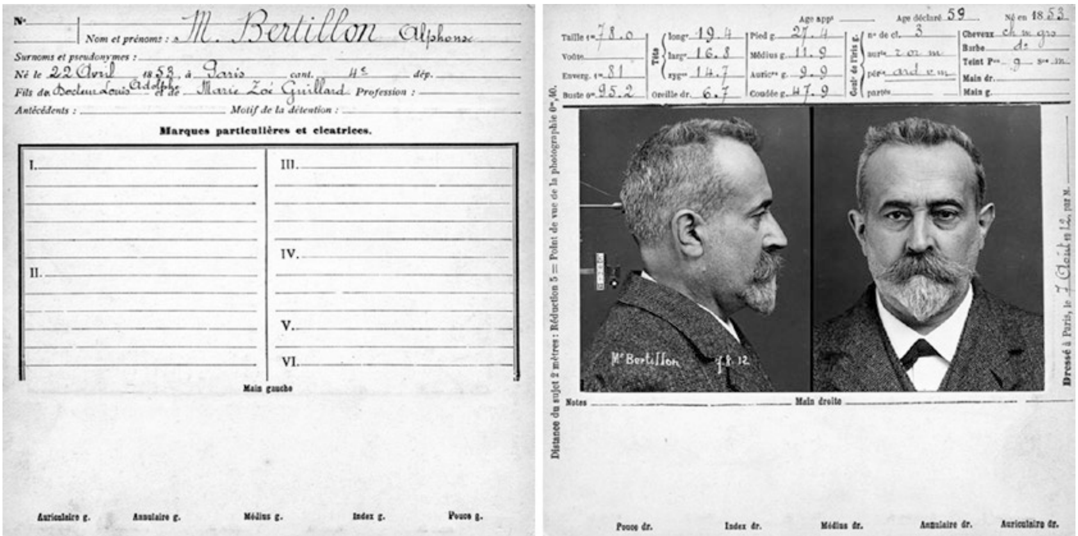
> *Photography makes aware for the first time the optical unconscious, just as psychoanalysis discloses the instinctual unconscious* [13].
>
> Walter Benjamin, 1931

The search for the "physiognomy" of the mentally "insane" goes back in medical history. With the advent of photography, cameras found a fast way into the psychiatric wards trying to "catch" outer manifestations of inner disturbances [21, 22]. Certain mental conditions were thought to be identifiable by the looks. Photographs were tools to communicate information about mental health: some psychiatric wards did it in a regular, standardized manner, while others did it erratically and unmethodically. It was a common practice to be photograph when entering an asylum. The justification included the possibility to identify a patient in case of escaping. Interestingly, some individuals refused to be photographed and some doctors supported their decision [23]. Early photography of patients was used to present emotions. Darwin's book *The Expression of the Emotions in Man and Animals* (1872) is a proof of this approach [24]. Before him, Hugh Welch Diamond (1809–1886) was one of the first to photograph the mentally ill patient, and mentally ill patients, and his enthusiasm with photography marks the appropriation of its use in this specific field of medicine [21, 25]. Today, these pictures can be a resource to understand the methodology with which Victorian doctors pretended to put a face to mental illness, how were psychiatric wards in that period, and who were the afflicted people.

4.5 Face and Law: Bertillon and the First Mugshots

Faces have always been of interest to science because of the possible hints into a person's character, for identification and in search of signs of expression. Some believe that expressions are a sign of emotions. Therefore, the face could be a mirror to the mind and soul. Photography in psychiatric wards and by police apparatus was a way of instrumentalizing the technique as part of the surveillance apparatus.

In 1890, Alphonse Bertillon (1853–1914) – a French police officer – applied anthropometry to improve the French police identification system. He proposed to complete the police record by including a *mug-shot* ("Mug" is an English slang term for face), a photographic portrait of the arrested person, from waist up which includes a front view and a side view (Fig. 4.16)



N°
Nom et prénoms : M. Bertillon Alphonse
Surnoms et pseudonymes :
Né le 22 Avril 1853, à Paris cant. 4e dép.
Fils de Docteur Louis Adolphe et de Marie Zoé Guillard Profession :
Antécédents : Motif de la détention :

Marques particulières et cicatrices.

I.
II.
III.
IV.
V.
VI.

Main gauche

Auriculaire g. Annulaire g. Médius g. Index g. Pouce g.

Age appt Age déclaré 59 Né en 1853
Taille 1m 78.0
Voûte
Enverg. 1m 81
Buste 0m 95.2
Tête long^r 19.4
larg^r 16.8
zyg^re 14.7
Oreille dr. 6.7
Pied g. 27.4
Médius g. 11.9
Auric^re g. 9.9
Coudée g. 47.9
Coul^r de l'iris g. n° de cl. 3
Cheveux
Barbe d°
Teint
Main dr.
Main g.

Distance du sujet 2 mètres : Réduction 5 = Point de vue de la photographie 0m,40.

Notes Main droite

Pouce dr. Index dr. Médius dr. Annulaire dr. Auriculaire dr.

Fig. 4.16 Mugshot of Bertillon M. (Figure under Public Domain, Wikipedia Commons CCBY)

12 CHAPITRE I.

Fig. 1.

Spécimen de photographie judiciaire anglaise.

l'être humain, et consulter les sciences naturelles et en particulier l'Anthropologie.

Fig. 4.17 Galton's method for taking frontal and profile photo of the face as it appeared in Bertillon´s book (1890), *La photographie judiciaire: avec un appendice sur la classification et l'identification anthropométrique* Paris, Gauthier-Villars (Open Access; book under Open Knowledge Commons)

[26]. In 1883, his system was adopted by the police in Paris and later became internationally popular [27]. Before him, Francis Galton (1822–1911), a half-cousin of Charles Darwin, had described this technique of generating multiple portraits in a rapidly and inexpensively way. His method was later published by Bertillon as "the English method" [11, 27] (Fig. 4.17).

Merging portraits taken of both sides of the face was possible thanks to an earlier invention from 1832 known as the stereoscope. Images like the one taken by Albert Neisser of a patient with syphilis are just one example of stereoscopic photography. [28]. This "fusion" of optical images was the embryo of depth perception, the beginning of today's 3D photography.

4.6 Post-Mortem: A Living Testimony of the Dead

By 1939, life expectancy was 35 years. Living and memorial (post-mortem) photography soon became desirable and an affordable way to keep the memories of the deceased person alive: it was like keeping alive not only the memory but the person itself. It was another embrace between science and magic, a mechanical mean of representation at the service of nostalgia.

As Barthes would state, it gave the opportunity to maintain a representation of a reality that once existed though "one can no longer touch" [29]. Past medical images are also the representation of somebody that was, and it is now gone. In the foreword of Roland Barthes's *Camera Lucida*, English writer Geoff Dyer says that probably the fascination of Barthes for photography had to do with death. An interest tinged with necrophilia, a "fascination with what has died but is represented as wanting to be alive" [29]. Cameras are, in Barthes words, clocks for seeing. Every photograph is a certificate of presence.

This concept was probably shared by people at the beginning of the era of photography when they took pictures of their deceased. Culturally, Victorians were closer to death than we are today; they honored their deceased and kept images around them; they did not plunge into denial [30]. For those that could not afford a painted portrait, a photograph represented the less expensive and almost providential opportunity to keep the loved one "at home" (Fig. 4.18). With very high mortality rates, it is no surprise that many of these photographs were of children. Bereavement photography of neonates, stillbirths, and children is still done to help in the grieving process (see Annex IMI Guidelines on Bereavement Photography (neonates, stillbirths and children) [31].

Fig. 4.18 Unknown maker, American, Post-mortem portrait of a young girl, about 1850, Daguerreotype, hand-colored. (Digital image courtesy of the Getty's Open Content Program, The J. Paul Getty Museum, Los Angeles, USA)

4.7 Medical Photography During War Time

Depiction of military medicine was another common use of the first years of medical photography. From 1861 to 1865, American Civil War [32] and later World War I (1914–1918) veterans were photograph in all the crudeness of their facial disfigurement and amputations. These pictures transformed patients into cases by objectifying their bodies [33]. They are living testimonies of the absurdity of war and the power of institutions on the bodies of soldiers. The use of photographs to register "medical conditions" used by the Nazis during WWII is another example of cruelty beyond description that left a testimony for trials and has become part of our collective memory.

War photographs had several uses. They were taken to prove a strange symbiosis of military technology and medical innovation, to present the artistic response of mutilation to prosthetic replacements, and to bring along a patriotic discourse.

In the Army Surgeon General's World War I rehabilitation journal, *Carry On: A Magazine on the Reconstruction of Disabled Soldiers and Sailors*, soldiers were photographed dressed up, engaged in everyday activities to conceal the reality faced by injured soldiers and reveal the persuade of the benefits of rehabilitation on war wounds [34].

Facial disfigurement occurring during War World I was very common. In Britain, the medical photographs from these patients were almost never shown outside the professional context of clinical medicine. Birnoff's believes it to be the result of British aversion to disfigurement. The worst loss was the loss of one's face as it was perceived as a loss of humanity [35].

4.8 Photobook and the Media

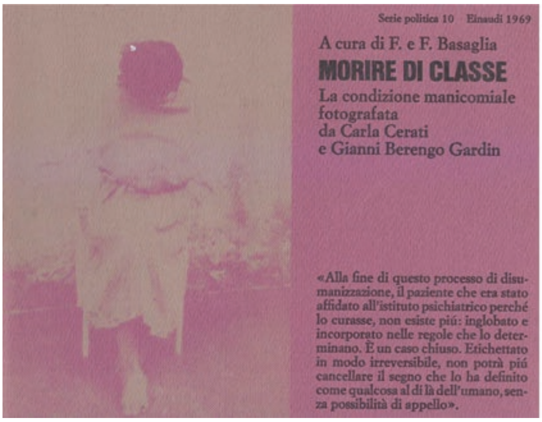
Roland Barthes, the French philosopher, believed that a photograph implied meanings and had the unique potential for presenting a complete and real representation of the world. He believed a photograph was a message [4] and not simply a "product or a channel but also an object endowed with structural autonomy" [4].

Medical photographs have been tightly intertwined in generating scientific, social, and cultural changes. An example can be found in the AIDS epidemic. The changes brought by HIV included the reshaping of conventional wisdoms in public health, research practice, cultural attitudes, and social behaviors [36]. The rapid development of effective treatments could not have occurred without activists and participation of patients. Photography was able to put "a face" to a disease, making affected people visible not only to the scientific world but also to the general public [37]. This was the case of the renowned images taken by photographer Therese Frare and her moving work with David Kirby and Peta (Fig. 4.19).

Some of the first dermatological atlases stigmatized the disease: AIDS-related photographs included in their legend information on sexual identity and age of the patient stating the relevance of these two pieces of information. This addendum of information which was otherwise not present in the image generated a classification of the disease into “the narrative of a highly problematic re-medicalization of homosexuality in the course of the early years of the AIDS epidemic” [38]. Photographs were almost always of white young homosexual men. They generated a connection even when the causes of the disease were not still completely understood. This “inherent” relation of AIDS-male homosexuality was later removed from captures presented in atlases. If, as Dalton and Galison point out, atlases “set the standards of a science in word, image, and deed” [5], it is also true that reconstituting histories from archives that were produced to do instrumental jobs becomes a risk [39].

Fig. 4.19 Peta in hospice, Columbus, Ohio, 1992. Photograph by Therese Frare (Courtesy of © Therese Frare)

Another interesting case of photobook which had an important social impact was *Morire di classe* (In English, To die because of your class) authored by Franco and Franca Basaglia with photographs by Carla Cerati and Gianni Berengo Gardin (Fig. 4.20). The pictures of institutionalized patients in psychiatric hospitals in several cities in Italy were able to show the pain, poverty, the suffering, and the imposition. They showed the violence on psychiatric patients as objects forcefully isolated into an asylum but also the violence of a society that does not want to see mental health and secludes individuals particularly those belonging to the poorest social class [40]. This book is part of the history of medical photography as it flattened the way for future photographers [41] and social denouncing of unacceptable medical situations.



Serie politica 10 Einaudi 1969

A cura di F. e F. Basaglia

MORIRE DI CLASSE

La condizione manicomiale
fotografata
da Carla Cerati
e Gianni Berengo Gardin

«Alla fine di questo processo di disumanizzazione, il paziente che era stato affidato all'istituto psichiatrico perché lo curasse, non esiste piú: inglobato e incorporato nelle regole che lo determinano. È un caso chiuso. Etichettato in modo irreversibile, non potrà piú cancellare il segno che lo ha definito come qualcosa al di là dell'umano, senza possibilità di appello».

Fig. 4.20 Cover from the first edition of the book “*Morire di classe*”, Einaudi 1969, by Franco Basaglia and Franca Ongaro Basaglia (left) and one the photographs by Carla Cerati and Gianni Berengo Gardin (Reproduced with permission of Carla Cerati, 2015 and Elena Ceratti 2020)

4.9 Women and Photography

Throughout history, women have been made invisible. The photography profession is no exception. From the very beginning, orthodox medicine used photography to represent itself creating a stereotyped medical image [42]. In this realm, there was no place for women doctors as doctors were always white men; women were always nurses or psychiatric patients.

The first portrait photography took conventions from art and domestic scenes. Nurses were frequently depicted working alone, "much as housewives did," or holding children. In the "family" pictures, they stood around male doctors. Depending on the period, they were placed standing behind or sitting on the sides.

If this was the imaginary for photographs of women in medicine, their recognition as photographers was not much more flattering. Names like Anna Atkins or Julia Margaret Cameron rarely appear in histories of medical photography. Another example is Lady Elizabeth Eastlake (1809–1893), an art historian, critic, writer, and pioneer of female journalism, who wrote in 1857 an essay under the title "Photography," for The London Quarterly Review (No. 101, April 1857, pp. 442–468) where she summarizes the scientific beginnings of photography [43].

Marginalized was also X-ray crystallographer Rosalind Franklin (1920–1958) who in 1951 was responsible for the image nicked named "Photo 51" that was shot by her PhD Student Raymond Gosling. This photo allowed her to deduce the basic dimensions of DNA strands to demonstrate that phosphates were on the outside of what was probably a helical structure. The image was shown to Watson J without her consent. He found in this image the missing piece of the puzzle to formulate the hypothesis on the nature of DNA, which later gave him and others the Nobel Prize in Medicine [44, 45].

In 2019, 29-year-old computer science doctor Katherine Louise Bouman contributed in the development and application of the algorithm called Continuous High-Resolution Image Reconstruction using Patch priors (CHIRP) which allowed to photograph for the first time a black hole (Fig. 4.21), a halo of dust, and gas found 500 million trillion km from Earth [46]. This image has revolutionized our understanding of one of the great mysteries of the universe [47]. As a curious note, 55 years before Bouman's achievement, the first digital camera was taking pictures from Mariner IV (1964), 5 years before Neil Armstrong stepped on the Moon. Those pictures were first taken by an analogical camera and converted into digital by a technology that does not exist anymore, the Vidicon tube (later substituted by the CCD sensor). The spaceship took 9 days to transmit the images. Decoding was so slow that the NASA team decided to hand-paint the first photo as they received the information! [48, 49]. A story worthy of an episode in the 1966 TV series Time Tunnel: "Travelling to the time of the first hand paint Atlases"! Again, science and art shaking hands (Fig. 4.22).

Fig. 4.21 Left: Rosalind Franklin (Reproduced with permission from Encyclopedia Britannica, Jewish Chronicle Archive/Heritage-Images) and right: Katie Bouman (Courtesy of National Science Foundation Multimedia gallery, All rights reserved)

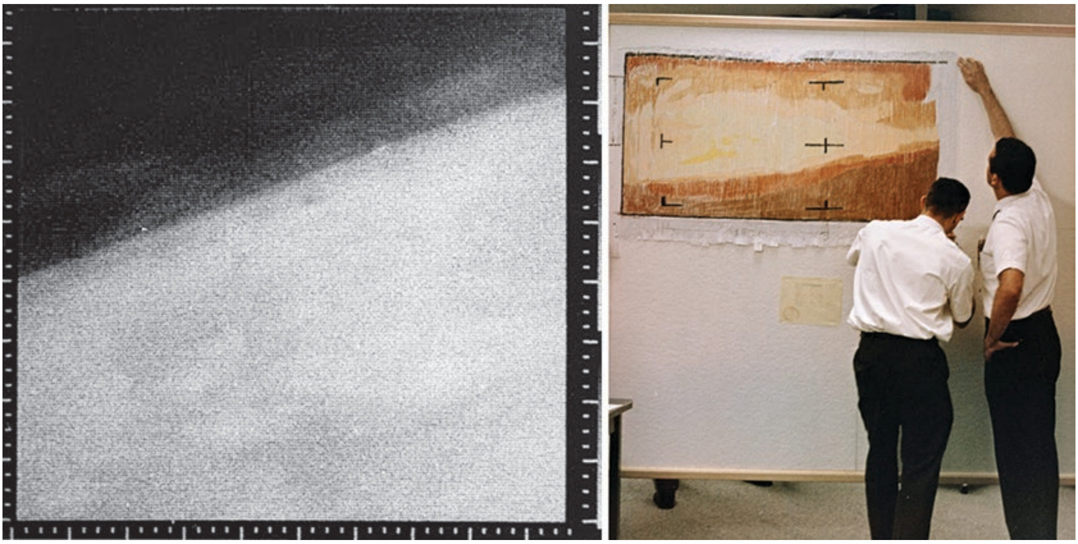


Fig. 4.22 Left: First picture of Mars, and right: painting made from the pieces of information as they were been received. (First Mariner 4 close-up image of Mars, enhanced to show haze, NSSDC Image Catalog and NASA/JPL-Caltech, figures under public domain)

4.10 The Undefined Limits Between Science and Art

The confluence of science and art has left us with uncertain boundaries where we can find "artistic" scientific images and "scientific" artistic images.

Standardization of medical photography pretends, among other, to define such limits; however, the use of black backdrops, the light concentrated on the subject, and the sharp contrasts seemed borrowed from chiaroscuro Caravaggio techniques of art. Using elements from scientific standardization, artists have produced extreme artistic images from nature. One such example is French photographer Pascal Goet (Fig. 4.23) and his photographs of bugs for his collection "Mask & Totem," where he found human symbolism represented in the colored patterns of insects. Each bug represents an imaginary mask, "a cultural bridge between our world and the world of insects" [50]. Photographs by plastic surgeon and photographer David Teplica [51] are another example of a confluence of art and science.

Fig. 4.23 Photograph of a Canthus, by Pascal Goet (Courtesy of Pascal Goetgheluck; series *Masques et totems*, insectes anthropomorphes. All rights reserved)

In the mid-twentieth century, photographer Lejaren Hiller Sr (1880–1969) was commissioned by the surgical/medical device company Davis and Geck to produce prints for a series called "Surgery through the Ages." These were pictorialist style of art photography that recreated medical scenes from posed photographs. Some of these scenes were also recreated by photographer Valentino Serra (1903–1982). These images were used to illustrate journals and became very popular, to the point of requiring reprinting of some journals to sell to those who wanted an extra copy. A possible explanation for these popularities was the fact that humanism was interpreted as the mark of a good physician [52].

In a publication in 2016, Aberer E et al. [53] used photography to document expression of human emotions. They photographed six individuals with different skin conditions: ichthyosis, psoriasis, exanthema, and skin cancer. The patients were asked to express their current emotions on a picture. They aimed at "objectivizing" patient's emotions by re-labeling the photographs as "discouraged," "mourning," "the scream" [53]. It could be argued that patients are asked to pose; however, these photographs are "capturing" their expectations which could or could not correspond to their real feelings. A further bias is the third-person interpretation of such information. It is still an interesting XXI century attempt to register mental conditions using photography as a technical instrument. It reopens the debate of "objectivizing subjectivity" and the continuous merge of science and art.

Anthea Gordon in her paper on Marlene Dumas, states that "medical photography, and in particular dermatological imagery, is often assumed to provide an objective, and functional, representation of disease and that it can act as a diagnostic aid. By contrast, artistic conceptions of the images of the body tend to focus on interpretative heterogeneity and ambiguity, aiming to create or explore meaning rather than enact a particular function" [6].

She brings this point to introduce us into the work of South-African artist Marlene Dumas (based in Amsterdam) that created some of her artwork from medical photographs. Gordon questions the assumption of photographic objectivity to "suggest that there is greater complexity and interpretative scope in dermatological images than might initially be assumed" [6].

Dumas's paints from photographs bring together the scientific attitude of a visual representation with the artistic one. The painting *Dead Marilyn* (2008) is based on an autopsy photograph of Marilyn Monroe which serves as a death certificate and objectivizes this moment. This portrait is "evidence": it is provoking way to confront us (the observers) with our mental image of Marilyn. "*Secondhand image generating a first-hand emotion*" [54]. By confronting us with a re-represented photograph of a patient with a skin condition, Dumas reverse our expectations and shows how a skin disease has a psychological burden and how an image of a physical illness represents a psychological condition [6] (Fig. 4.24).

Dr. Hector Padula, a Venezuelan photographer and anesthesiologist, is the author of IPA WAYUMI, a photobook that delves into the life of the Yanomami people, in the Upper Orinoco. He went to work with this group, in the Venezuelan Amazon, 30 years ago, over a period of 2 years. He started taking photographs of his work with the only intention of "stopping time," the preservation of the instant. His photographs transcend mere medical documentation and still illustrate medical conditions. Through his art, it delivers a powerful message of awareness filled with empathy (Fig. 4.25) [55].

Fig. 4.24 Left: Dead Marilyn, by Marlene Dumas. (Details work: Dead Marilyn, 2008, oil on canvas, 40 × 50 cm; Credits collection: Kravis Collection; Copyright work and courtesy image: Marlene Dumas; Credits photography: Peter Cox, Eindhoven). All rights reserved; Right: Photograph of Marilyn Monroe, taken at the morgue. (Figure under public domain)

Fig. 4.25 “He wanted to hear my heart, just like I wanted to hear his. That was the deal to take this image”. Yanomami adolescent from the village of Doshamoshateri, Siapa river, Alto Orinoco on the venezuelan Amazon. (Photography courtesy of Héctor Padula S, 1990. Ilford film 400. Digitalized from negative. All rights reserved)

4.11 Historical Archives

Photography, archive, and memory are intimately connected. Memory and photography both involve the process of recording images that may be used to recall the past [56].

There are numerous medical archives worldwide, and they have been presented in different formats: paintings, photographs, wax molds, sculptures, audio recordings, films, text-based archives, and manuscripts. Some are available online, others are digitalized but not available on the website, and some are still visible in their original formats. They can be found in specialized museum or libraries as well as in public and private collections; access is sometimes allowed to the general audiences; in others, only physicians/historians/curators are permitted to access them. Medical imaging archives have always been a precious source of learning, from the first atlases by Vesalius to the modern photographic digital anatomy found in the “Visible Human Project” which contains hundreds of cross-sectional photographs of the human body, taken to facilitate anatomy visualization applications (Fig. 4.26).

Medical photographic iconography is to be found as daguerreotypes, painted photographs, or wood engravings done after a photograph, just to mention a few. One such collection is the Wellcome Collection [57] in London,

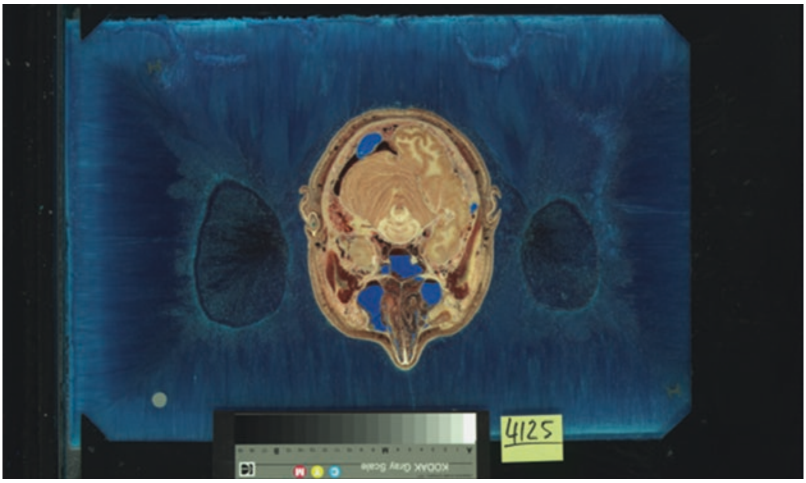


Fig. 4.26 A full color anatomical images from The Visible Human Project (Courtesy of the U.S. National Library of Medicine)

which is one of the world's major resources for the study of medical history and the medical humanities.

Photographs can be used as a historical record of the "how it was" giving us a new understanding of the past [42]. But looking at these photographic collections from the past is also prying into someone's intimate moments. That picture was most surely taken without the consent of the person involved, of a person that is now probably deceased. Even if the consent was actively sought, it was usually not specified the use, and it was obtained mostly for upper-class patients. Probably, low social status background, minorities, mentally impaired, and many women were not even asked. Protecting the patient's privacy followed historical, social, and cultural conventions including issues of which anatomical area could be exposed. In clinical photography, power has always played an important role [58]. In fact, it was not until 1957 that the term "informed consent" was first used but needed 10 more years to become established as a standard of care [59].

Did we have the right to take those pictures in the first place? Do we have the right to expose those pictures to the general public? These photographs give information on the physical and mental state of a human being, and since many pictures were taken of the rarity—*the freaks*—they end up exposed in a circus-like fashion. This is the reason why these collections have been labeled by historians and curators as "sensitive" collections [58, 60].

In the case of the Wellcome Library, they have engaged with this problem by developing a practical policy on research access to personal data present in their collection [61]; approximately 50% can only be viewed by application as images taken in the late nineteenth century and the person in the photograph certainly deceased, fall outside the scope of the Data Protection Act (DPA). The Wellcome Trust policy commits to assessing the data for sensitivity from an ethical perspective: unrecognizable images are made openly accessible (within the library), and the recognizable images available have restricted access. They are conscious of the possible risk of "censorship." Others, like Michael Sappol, from the US National Library of Medicine believes instead in free access to all medical photographs [62].

Facilitating non-medical audiences to view the medical past iconography as mere source of curios objects and give free entrance into peoples' privacy does has its consequences. The suffering of some becomes the entertainment of others. The audience is a "voyeurs." Exposing others afflictions can be a form of visual violence. The appropriation of such images to be used to create monsters for the entertainment of gamers shows lack of empathy and the exploitation of the shock value of a disfigured face or body [62]. As Susan Sontag would say: "Our failure is one of imagination, of empathy:

we have failed to hold this reality in mind" [63]. In the video game BioShock (2007), part of its disturbing artwork was based on digitalized disfigured World War I veterans. Biernoff S states in her paper on *Medical Archives and Digital Culture* that moral choices and consequences are built into the game and the use of recognizable suffering individuals for the sake of entertainment can only be a perverse transgression of the pledge not to forget [64].

For Tagg J, the camera is never neutral: photographing "abnormal" physiognomies of patients becomes a burden of subjection. The archive of repetitive images is an accumulation in which "the smallest deviations may be noted, classified and filed" [12].

And still, museum exhibitions of clinical photographs can be the opportunity to bear witness of difficult experiences and help in the understanding of human suffering [58].

Can we as medical photographers of the present guarantee that our patient's images will not be part of a BioShock videogame of the future?

4.12 The Coronavirus Pandemic

In 1963, a young and bright Scottish woman by the name of June Dalziel Almeida (Fig. 4.27) pioneered a technique to better visualize viruses. She used antibodies to aggregate the virus in a technique called immune electron microscopy (IEM) [65]. By 1966, June Almeida and David Tyrell identified a group of viruses that were causing respiratory conditions. Together with Tony Waterson named the newly discovered creatures, coronavirus [66]. Prof. Hugh Pennington declared to the Herald (March 2020) that "without her pioneering work things would be slower in dealing with the current coronavirus outbreak. Her work has speeded up our understanding of the virus" [67]. Her immune electron microscopy (IEM) innovations and insights contributed not only in the coronavirus research but also in diagnosing diseases like hepatitis B, HIV, and rubella. Her electron micrographs and her technique were and still are used. Time has shown how much we owe to her work (Figs. 4.28 and 4.29).

Fig. 4.27 Dr. June Almeida, the Scottish virologist who was a pioneer in virus imaging, identification and diagnosis. She was the first scientist to identify and photograph a group of virus later named coronavirus. (Photograph courtesy of Joyce Almeida, All Rights reserved)

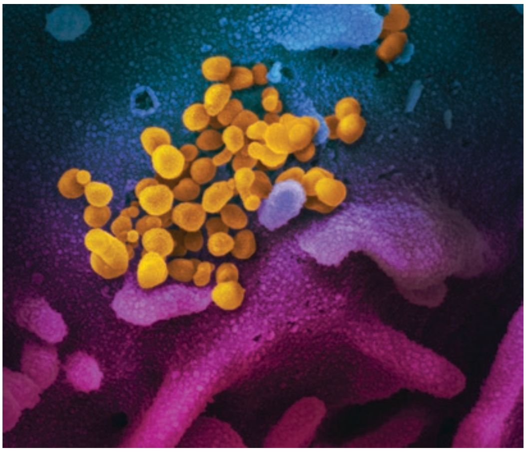


Fig. 4.28 COVID 1 This scanning electron microscope image shows SARS-CoV-2 (yellow)—also known as 2019-nCoV, the virus that causes COVID-19—isolated from a patient in the USA, emerging from the surface of cells (blue/pink) cultured in the lab. (Credit: NIAID RML)

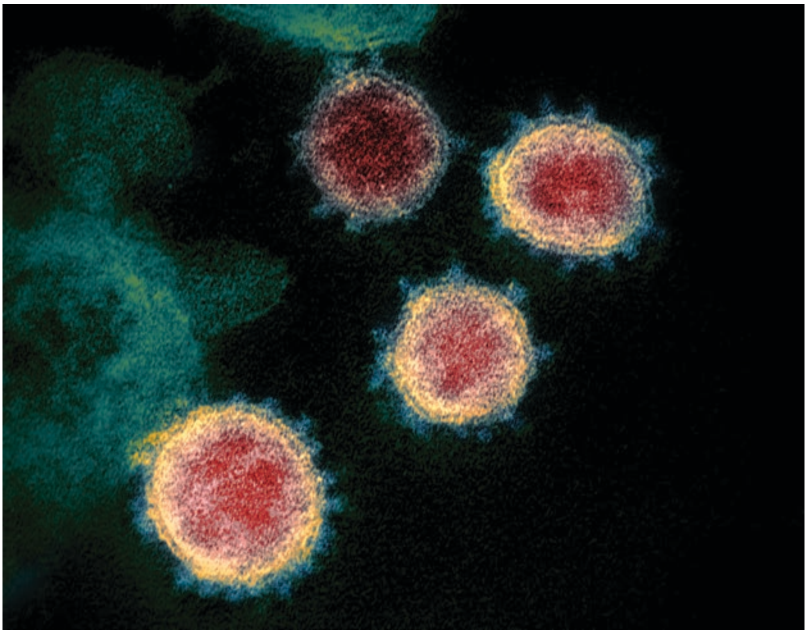


Fig. 4.29 COVID 2 This transmission electron microscope image shows SARS-CoV-2—also known as 2019-nCoV, the virus that causes COVID-19—isolated from a patient in the USA. Virus particles are shown emerging from the surface of cells cultured in the lab. The spikes on the outer edge of the virus particles give coronaviruses their name, crown-like. (Credit: NIAID-RML)

4.13 Conclusions

Photography has changed the way we see the world. It generated a complete change in paradigms, transforming information, democratizing knowledge, changing the perceptive toward patients and their health, and empowering those who posses the images over the subjects. This brief history is just a few brush strokes of a complex relationship whose impact we are still witnessing. We hope this introduction has drawn the path to the amazing world of medical photography.

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Part II

Approaching the Subject

5

Ethical Aspects of the Use of Photography in Clinical Medicine

Sarah Mattessich and Jane M. Grant-Kels

Contents

5.1 Introduction

Photography is considered the standard of care in many visually oriented specialties, particularly dermatology, ophthalmology, plastic surgery, maxillofacial surgery, and wound care. In these settings, photography is integral to providing the best possible patient care and thereby adheres to the ethical principle of beneficence: taking action for the benefit of the patient. The irreplaceable advantages of photographs in these fields contribute to saving lives and health care dollars as well as potentially reducing clinical morbidity.

The use of photography has been documented to enhance patient care in the areas of diagnosis, treatment, and education. For example, total body digital skin imaging is a technique in which the entire cutaneous surface area of the body is photographed and assessed over time in conjunction with dermoscopic evaluation. This method identifies new lesions or subtle changes in melanocytic lesions that could be missed by a traditional full body skin exam without baseline images, thereby improving early detection of melanomas, saving lives, and reducing unnecessary excisions [1–4]. Additionally, photography is proven to reduce patient anxiety and the incidence of

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wrong-site surgeries [5, 6]. Serial imaging can assist providers in monitoring response to therapies long-term, such as laser therapy, and the progress of chronic inflammatory skin disease, like psoriasis and atopic dermatitis, thereby enhancing a personalized approach to the patient's treatment [7]. Digital images can also be readily shared between providers for consultation, ultimately improving diagnosis and speed of clinical management [8]. In primary care and dermatology, photography is a promising technique for modifying patients' risk-related behaviors. For example, a Cochrane review showed that photography in conjunction with clinical counseling was especially helpful in improving patient participation with at-home skin exams, in discouraging the use of tanning booths, and in adhering to sun protection behavior [9].

Unfortunately, the necessary integration of photographs into patient and public records brings forth a number of ethical dilemmas, especially in the era of electronic medical records (EMRs). Failure to honor patient autonomy, privacy, and informed consent—for instance, by publishing a photograph without the consent of a patient—can damage the integrity of the physician-patient relationship. Lack of universal photography technique protocols can lead to an inability to provide the best medical care possible, as photographic settings must be reproducible in order to be comparable at follow-up. Unregulated photograph ownership, usage, and storage may also infringe upon the privacy of the patient. Additional complications occur when the site of the picture includes "private" areas (such as women's breasts) or when the patient is unable to give their consent or express refusal, such as a child or adult with intellectual disability.

Approaches to dilemmas involving the use of photographs in medicine can be guided by the implementation of universal ethical principles. The Hippocratic Oath provides one of the oldest ethical guidelines for moral and professional patient care, including the principles of beneficence, nonmaleficence, autonomy, justice, confidentiality, dignity, and honesty (Table 5.1). However, definitions of these principles can be vague and their application open to the interpretation of the physician, especially when a legal solution does not exist. Professional societies, including the American Medical Association (AMA) and European Council of Medical Orders (ECMO), have expounded on these principles, updating them to reflect changes in societal attitudes and values. Although both societies address elements of medical photography, application in clinical practice varies widely. Recognition, discussion, and education of ethics in medial photography may encourage standardized approaches and appropriate patient care, especially when difficult ethical dilemmas arise.

Table 5.1 Summary of medico-ethical principles

Ethical principles	
Beneficence	Provide the best patient care possible; the welfare of the patient is primary above all else
Nonmaleficence	Do the least harm possible
Autonomy	The patient's right to direct their medical care without coercion
Justice	All patients have a right to the same access and quality of medical care
Confidentiality	The patient's right to privacy
Dignity	Respect of the patient
Honesty	Truthfulness regarding patient care and outcomes; informed consent

5.2 Ethical Dilemma #1: Breech of Privacy and Mass Distribution

Risks of medical photography include breech of privacy, identification of the patient photographed by non-clinical persons, dissemination to unauthorized parties, psychological harm to the patient, and inability to revoke a photograph once published in a medical journal or on the internet. Digitalized photographs are naturally at risk of distribution through the pervasive internet, which is increasingly more plausible as hospitals transition to electronic medical records (EMRs).

5.2.1 The Principles: Patient Autonomy, Confidentiality, and Informed Consent

Breeches of privacy and mass distribution can be mitigated through application of the principles of patient autonomy and informed consent. Patient autonomy is the ethical principle of ensuring the patient makes fully informed decisions about their healthcare without intrusive influence or fear of retribution. Within reason, the patient should always have a sense of control over their medical care and information. Therefore the concept of autonomy extends to the capture and storage of clinical photographs [10].

The right of the patient to have their photographs remain private is legally secured under the Privacy Rule of the Health Insurance Portability and Accountability Act (HIPAA), which protects the use and disclosure of identifiable patient data. HIPAA states that patients may authorize specific uses of identifiable information, demonstrating that patient autonomy is intertwined with the right to confidentiality. Consequently, the physician is ethically and legally mandated to use photographs for only the purposes that are agreed upon by the patient during the informed consent process, during which the potential uses of the images acquired were specified. This fact should be reiterated to the patient for their reassurance. For example, a patient can choose to allow her photograph to be uploaded to her electronic medical record but not shared for publications or medical education [11].

Patients are generally more comfortable sharing their clinical photographs for multiple uses (i.e., education, publication) if the photographs are de-identified [12]. Multiple guidelines are available that detail proper de-identification techniques [13, 14]. Any identifying and unique tattoos, clothing, jewelry, or recognizable natural "landmarks" should be cropped or masked. There is a general consensus that concealing only the patient's eyes in a facial photograph is insufficient and that as much of the face should be concealed or blurred as possible. One recommendation is that both eyes and eyebrows be concealed at a minimum if possible [14]. Following the HIPAA Privacy Rule, the patient should be allowed to review the final photograph for approval [11].

An ethical dilemma may arise when a patient does not want their de-identified photograph used for research or educational lectures. According to HIPAA, once medical information is de-identified using the proper techniques, it is no longer legally considered "protected health information" [11]. This implies that the physician could, in theory, use the photograph at his or her discretion. However, honoring the agreement of the informed consent process is imperative to preserve patient trust, privacy, and autonomy, and the physician should abide by the patient's wishes.

5.2.2 Patient Autonomy and Informed Consent Applied to Medical Photography

The process of informed consent was designed to safeguard patient autonomy. It ensures that a patient both understands and competently agrees with the physician's plan for his or her care, empowering the patient to take part in clinical decision-making [15]. Informed consent can be written or verbal; however, written consent is preferred because it provides a concrete record should it need to be reviewed. Patients generally prefer a written document over verbal consent [12].

Although there is not a standardized consent form for medical photography, many medical offices have created their own versions. Free templates that include the basic elements of informed consent for medical photography are also available online for download [16, 17]. These basic elements include the following:

1. Purpose of the photograph
2. Description of the process
3. Disclosure of benefits to the patient
4. Disclosure of risks to the patient
5. Disclosure of alternative approaches, including no photograph
6. Description of how the photograph will be stored
7. Description of each specific use intended for the photograph

While the physical form is intended for the patient to read and sign, the provider has the ethical responsibility of engaging in a dialogue to educate the patient about the process while assessing the patient's understanding. Physicians who take the time to explain the photography process with the patient will likely improve patient comprehension and confidence in the process [18]. The patient should understand why the photograph will be taken, how the photograph will be obtained (including what area of the body the physician is intending to capture), how the photograph will enhance the patient's medical care, and what risks are possible as a result of the process [10, 16].

The physician should disclose that the patient has the right to decline the photograph outright or abstain from any specific use of the photograph, emphasizing that photography is completely voluntary and refusal will not significantly compromise the quality of the patient's clinical care going forward. The patient also has the right to revoke their decision at any time. The physician must reassure the patient that if they refuse photography or use of the photographs for education or publication that there will be no retribution or alteration in the patient-physician relationship. If a patient declines photography, a detailed written description in the patient's chart can be used as an appropriate alternative [10, 19]. The note should describe the appearance of the lesion(s) or areas of interest and include measurements relative to anatomical sites to enhance future identification of the site(s).

Special arrangements should be made for patients with legally compromised "competency" for medical decision-making, including patients who are cognitively impaired, have an intellectual disability, or are minors (less than 18 years old in most states). In these scenarios, the provider should seek a proxy for obtaining consent. For instance, a child's photograph would be consented by a parent or legal guardian. Failure to do so could result in legal consequences for the physician [15, 16, 20, 21].

5.3 Ethical Dilemma #2: Privacy of the Patient—Sensitive Area Photography

While a majority of surveyed patients are accepting of medical photography [12], many will rightfully feel uncomfortable during photograph acquisition. This is particularly true for photographs of sensitive areas (genitals, female breasts) or full body imaging, during which the patient remains undressed for much of the session.

5.3.1 The Principle: Non-maleficence

Sometimes the best medical approaches are unavoidably uncomfortable or harmful to the patient, and physicians have a moral responsibility to ensure that their intervention causes the least amount of harm possible. Protecting the patient in this manner is upholding the ethical principle of non-maleficence, or "doing the least harm possible."

5.3.2 Non-maleficence Applied to Medical Photography

To maintain patient dignity and reduce patient discomfort, the photographer must conduct the photography session both professionally and compassionately. In a 2014 survey study, patients noted that they significantly preferred to have a doctor take their clinical photographs, most likely as this reduces the anxiety associated with interacting with someone they do not know as well or at all while in a vulnerable setting. Patients were also more comfortable when the photographer was the same gender and when a clinic-owned camera was used for photo acquisition compared to a physician's personal cell phone [12]. When a doctor is not available to obtain photography, a designated "clinic photographer" should be trained to take medical photographs appropriately and be sensitive to the needs of each patient [10, 22].

Additionally, appropriate draping techniques should be used so that only the minimum necessary area is exposed and photographed.

For any photography session, whether the patient is fully clothed or not, the patient should be offered to have a chaperone present. Some institutions maintain a policy of using a trained chaperone for all photography sessions for the purpose of protecting both the patient and photographer [23]. Offering a chaperone helps alleviate potential embarrassment, promotes a professional environment, and increases comfort for both the patient and the photographer. However, sometimes patients prefer not to have more than one other person in the room. Additionally, a trained chaperone is not always a feasible option for a medical office, causing the photographer to improvise. Guidelines vary regarding the appropriateness of an unplanned chaperone [23]. Specifically, there is ambiguity in whether or not relatives, friends, or administrative staff can serve as chaperones. Views also vary on whether or not chaperones must be medically trained, of the same sex as the patient, and if there is an age cutoff under which a child is required to have a chaperone [24]. The best approach is to engage the patient in a private conversation about the use of a chaperone.

5.4 Ethical Dilemma #3: Privacy of the Patient—Photograph Storage Issues

One of the challenges with digital photography storage is the cumbersome process of transferring a photograph from the digital camera to the electronic medical record. Uploading images from camera to computer to electronic medical record can lead to a number of errors, including mislabeling filenames or metadata, deleting pictures, or failure to upload to the EMR, especially in the setting of a fast-paced clinical practice. Failure to delete images from the camera or computer can also lead to a potential breech in patient privacy and therefore methodical procedures should be instated for photo transmission [25, 26].

To address these issues, EMR systems are developing remote access platforms for mobile devices that have the capability to immediately download images into the progress note via the internet. However, this limits photography acquisition to the mobile device, which may compromise the image quality that is attainable with a digital camera. Additionally some EMRs have developed the ability to afford access to the images only with the use of a special password to enhance patient privacy and access to the photos only by clinicians who need to review them.

5.4.1 The Principle: Informed Consent of Storage Systems

During the informed consent process, all options for photograph storage should be disclosed, including on an EMR system, on a “secure” clinic computer, or as a printed hard copy for a “shadow” paper medical record.

5.4.2 Informed Consent of Storage Systems Applied to Medical Photography

Each method of storage has imperfections and risks that should be discussed with the patient. For example, photographs in EMRs are usually accessible to clinical staff across practice areas in the same network, leading to decreased privacy. Pictures stored on secure clinic computers may be forgotten, mislabeled, or misfiled. Additionally, they are more difficult to share securely when a consult is needed with another physician. Lastly, printed pictures for a “shadow” paper chart, although more secure if locked up, lose much of the detail and quality of digital photographs. This may affect the ability of the physician to make an adequate assessment when reassessing the patient at follow-up. Ultimately, the patient should decide which storage method they prefer, and this should be documented on the informed consent and in the clinical note.

5.5 Ethical Dilemma #4: Lack of Technical Standardization

Almost every aspect of the photography process should be standardized, including the type and brand of camera, the technical settings, the studio/room setup and lighting, and the positioning of both the patient and the photographer. Unfortunately medical photography standards are widely underutilized and variable. A survey of 153 dermatologists showed that only 23.7% adhered to a photography protocol in their clinic [27]. Without a consistent technical protocol, the original purpose of the photograph becomes obsolete.

5.5.1 The Principle: Beneficence

Beneficence is the ethical medical principle that mandates taking the best course of action for the benefit of the patient. Photography is the standard of care in many specialties, and therefore physicians should practice beneficent care by utilizing photography in these settings.

5.5.2 Beneficence Applied to Medical Photography Standardization

Standardization of medical photography is imperative for accurate documentation and to guarantee high-quality, comparable, and transferable images. Utilizing standardized photo acquisition increases patient comfort and security that photography is part of the medical process. Standards improve clinical care such that the detail and quality of the photo is sufficient for the physician to appropriately assess the current condition and subsequently monitor the disease state or treatment over time. For instance, varying color calibration settings, lighting, or magnifications drastically alter the appearance of the same subject [26]. Figure 5.1 shows how an image is affected by various light sources.

While there are no universally accepted guidelines for standardization, there are a number of published recommendations [22, 28–32]. These guidelines suggest appropriate technical settings for image resolution (the number of pixels in a photo), color resolution and calibration, and reproduction (magnification) ratios. They also recommend appropriate background and lighting, which can affect the integrity of a photograph and should be made as reproducible as possible. Detail to the positioning of the photographer, patient pose, and the color and reflectance of the background material are also critical (Table 5.2) [22, 28].

Identifying a designated space to obtain clinical photographs and obtaining a skilled clinic photographer will minimize variations in photography. When a skilled clinic photographer is not available, a staff member may be designated as the clinic's lead photographer; this person will be

Fig. 5.1 Subject photographed using different light sources: (**a**) Sunlight (window); (**b**) mixed fluorescent lights and sunlight (window); (**c**) fluorescent lights; (**d**) mixed fluorescent and incandescent lights; (**e**) incandescent lights (*Courtesy of Dr. Justin Finch*)

Table 5.2 Recommendations and technical instructions adapted from Quigley EA, et al. [28]

Recommendations for camera-acquired clinical images	
Image spatial resolution	800 × 600 pixels (American Telemedicine Association, 2012) 2000 × 1500 (Primary Care Commissioning, UK, 2013)
Color resolution	24 bits (American Telemedicine Association, 2008)
Reproduction (magnification) ratios	Calculate the correct lens setting Adopt a standard distance between patient and camera lens
Color calibration	Adopt a clinic protocol for color calibration procedure
Image output	Match display monitor resolution to image resolution, and Calibrate monitors for luminance, gamma, and white point
Lighting	2 studio floodlights set up at 45° angles to and 1–1.5 m in front of the patient
Background	White, black, blue, gray, or neutral colors and nonreflective
Camera position	Record the distance between patient and camera
Patient pose	Varies based on area of interest

required to learn and oversee the appropriate conditions for photo acquisition and the process of uploading and storing patient photography at the medical office or facility [22].

Post-acquisition processing and photograph storage require standardization as well, including details of file format conversion, compression, and metadata [28, 29]. Digital Imaging and Communications in Medicine (DICOM) exists as an international standard for images acquired from medical devices such as CT scans, X-rays, and MRIs, with emphasis on specifications that allow these images to be transferable between different networks. However, DICOM does not specifically provide standards for camera-acquired digital photography, which can greatly compromise clinical benefit [33]. Furthermore, standardization is difficult to achieve when images are acquired on different devices (i.e., digital cameras (recreational or professional), smartphones, or tablets). There are published resources for clinicians that detail specifications for appropriate affordable clinic cameras [34]. However, with the vast improvements in image resolution on mobile devices, physicians are increasingly using these devices due to their accessibility, ease of use, and improvement in workflow.

It is the moral responsibility of the photographer not to edit the image in such a way that deceives the observer. This is especially important in academic publishing and patient marketing. Most academic journals will provide requirements for photograph specifications (such as resolution) and strongly discourage any editing except that which attempts to protect the identity of the patient. This ensures the integrity of the author's work and observations. Photographs are also commonly used to market procedures or therapies to patients. Editing an image to enhance an outcome is dishonest and breaks the trust that is central to the physician-patient relationship.

5.6 Ethical Dilemma #5: Beneficence Vs. Patient Autonomy

The principles of patient autonomy and beneficence in medical care are highly intertwined and known to conflict. Medical approaches should be tailored to allow for the most appropriate care that complies with the patient's wishes.

5.6.1 Beneficent Care Vs. Patient Autonomy Applied to Medical Photography

Consider a mother who refuses to have a baseline photograph taken of a congenital melanocytic nevus with unknown malignant potential on the genitals of her infant. Acquiring a photographic series for monitoring the lesion has clear medical benefit for the patient; however, the mother's fear of the photograph's accessibility and dissemination via the internet cause her to be wary of allowing a digital photograph to be uploaded to the EMR.

Ultimately, the mother's right to privacy and autonomy over her son's medical information takes precedence. The physician can use alternative approaches to tracking her child's skin lesion that would be more acceptable to her [10].

Similarly patients may refuse photographs of their genitals, breast area, or face because of similar concerns of privacy or cultural practices [12, 35, 36]. For instance, Islamic standards restrict a stranger's visualization of a woman's body to only her eyes and hands unless medically imperative [36]. Even though the lack of photographs might complicate and hamper future care and follow-up, the patient's right to autonomy and privacy must prevail. Detailed descriptions of the lesions with measurements are then recommended.

5.7 Ethical Dilemma #6: Lack of Guidelines for Mobile Technologies and Internet Forums in Medicine

There is a need for a number of new social, legal, and ethical guidelines for use of new technologies and social media in patient care [37, 38]. In most modern-day homes, smartphones, tablets, and other mobile devices are commonplace, and, not surprisingly, these popular devices have infiltrated the medical field.

5.7.1 The Principles: Beneficent Care, Patient Privacy

Utilizing mobile devices and internet forums creates novel opportunities to provide faster and more integrated patient care. However, acquiring and sharing photographs in these formats inevitably risks patient privacy.

5.7.2 Beneficent Care Vs. Patient Privacy Applied to Medical Photography on Mobile Devices and Internet Forums

Smartphones have become increasingly common for a variety of medical purposes [38–41]. Using a smartphone as a clinic camera is especially alluring as it saves time and can now take pictures with more than the minimum required quality to adequately assess and review the lesion or submit to an academic journal. Additionally, the smartphone platform makes sharing images between patients and doctors extremely effortless, bypassing the burden of uploading and transferring images from a traditional digital camera to a computer. A majority of surveyed dermatologists admit to receiving and sending email and text photographs to and from patients and colleagues [27]. If a phone is used to obtain the images, the patient must be reassured that these will not be stored on the phone. Potential loss of a cell phone or access of non-medical persons to this phone that contains images of patients will likely be a concern of patients.

While there are benefits to this mode of imaging, the risk of breech in patient privacy is greatly amplified. With smartphones and tablets being so readily connected to email, "apps," and social media, there is a need for extra security measures to protect patient photographs. Physicians should take care to comply with HIPAA policies and utilize EMR platforms that securely transfer images from mobile devices [38].

The ethics of using social media, such as Facebook or Instagram, or other digital forums to share patient photographs is controversial. While there is a benefit to potentially accessing numerous clinical opinions through a digital discussion, patients are sensitive to having their photographs shared online even if they are de-identified [12]. Breech of privacy, even on a proclaimed "secure" website, will always be a risk. Additionally, knowing the ownership and privacy permissions of the forum is extremely important, as some will default the account to a setting that grants the forum access to republish photographs for any reason. Physicians should take care to respect patient privacy and not engage in these forums unless specifically consented to by the patient [42].

5.7.2.1 Bottom Line

Photography has become an integral part of medical care and as such is subject to the medicoethical guidelines that result in respectful and appropriate patient care. Patient autonomy and informed consent ensure that the patient has authority over his or her medical information. Physicians must take care to comply with security features to protect patient privacy and dignity, especially with online, digital photography, and undertake medical photography with standards that allow for beneficent, accurate medical interpretation. Most importantly, a compassionate approach to photography that respects the patient's privacy and wishes will enhance patient comfort and trust in medical photography and in their physician.

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Treating the Patients: The Photographic Approach

6

Marisela Hernández and Paola Pasquali

Contents

6.1 Introduction

> *I think it does, a little, hurt to be photographed*
> Diane Arbus, letter to Marvin Israel [1]

What does it feels being photographed by a physician? We shall focus on what being-photographed-by-a-physician could mean, assuming that the skin as well as the photography constitute wide cultural fields of representations delimiting their senses on particular contexts, in our case, the medical one.

The context of our interest adopts its forms and meanings in a particular place, the doctor's office, where two main *actors* relate to one another, the doctor and the patient mediated by an *artifact*, the photographic camera with a specific *purpose or function*, to take photos of a certain part of the body (a skin lesion, for instance) in order to add information worthy for diagnose and treatment of such health problem.

This medical act is performed under the script of the cognitive-instrumental rationality. Rationality can be defined, following Habermas, as:

> "(…) a certain way in which subjects gifted by word and action acquire and use knowledge. Rationality lives in the way people (…) use certain knowledge and how symbolic expressions are used (…) A cognitive-instrumental rationality (is) reinforced by pragmatic criteria of success and technical control of a situation" [2].

Such rationality dictates ways of acting ruled by what has been called *Science and Technic*, in our case, what historically and culturally corresponds to contemporary medicine, which estab-

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lishment as knowledge-power practice has been situated by some historians by the end of eighteenth century [3].

Medicine defines itself as a science for curing/healing, a particular goal embodied in the figure of the physician, leaning on a technic, in our case, the photographic camera and all its related technical possibilities. The action of taking a medical photography is also regulated by related cognitive-instrumental rationality: the medical/legal one. It is materialized in our stage by the official post of the American Telemedicine Association, entitled "Photography Guide for Teledermatology," hanging at one of the medical office walls of one of the author's office (PP) and which states:

> "Center anatomy in frame. Include only clinical information (…) Keep camera level with anatomy. Do not angle up or down".

In consequence, photographing should limit to take a portion of the injured skin, the one that provides clinical information. In such doing delimits the body to its anatomy and its pathology, that is, to meanings reduced by and to, the camera frame, which in turn is regulated by the frame of medical looking, in a cultural practice that Foucault [3] named body "medicalization": the reduction of the body significance to its medical relevant functions; a body which gets ill and receives treatment by parts, by medical specialties; a body that turns into object, that is, separated from subjectivity from the whole person to become a medical case.

> "The Clinical Medicine presents itself as a key issue in the ways that human beings understand who they are. In this situation, medical discourse reveals itself as a fundamental tool to understand subjectivity in the objective level of the somatic" [4].

As we open the spectrum of the meaningful, and focus specifically on the skin, we find that it has literally embodied existential senses, that is, has been a symbolic field, because:

> "In the symbol (…) a sensitive, concrete, perceptible aspect, knits together with the meaning that such an aspect evokes and reveals. It could be said that the perceptible or figurative face of the symbol intends to indicate and distinguish in direct and clear ways. But is in its other face, suggestive and ambiguous (…) where the meaning can be understood; implying that it cannot be completely nor directly reached, because it exceeds the figures that it intends to embody" [5].

From an existential approach, skin introduces and contains the whole person, here and now. Skin makes possible the perception of the Person, its materialization. The skin gives perceptual clues of *yourself* and *myself*: visibility, sound, smell, taste, touch [6].

To touch is the definitive sense to corroborate the existence of self, of others, and of things. To touch implies the abolition of distances to perceive, to be-in-the-World: to touch supposes the immediate, that is, the non-mediated contact with *myself* and the other(s). It is also the case of the sense of taste. In contrast, to see, listen, or smell, a certain distance or detachment is required.

Also as *container*, the skin means contour, silhouette, permeable frontier, and a bridge between the world and me. Thus, the skin becomes communicator.

As pointed out, we take as reference the study of Pasquali et al. [7] to interpret the delimitation, contextualization, and, in a certain way, the reduction of the senses of the skin during the medical act. In such doing, a simile given by one of the doctors has been very helpful. She shared: "Patient permission to be photographed by the physician is equivalent to allow a blood test. The patient gives a part of her/his skin as well as a part of her/his blood only for the sake of her/his health."

Blood, in the context of taking a sample for medical testing, has a clear instrumental meaning: delimits or reduces its complex cultural senses to clinical ones (that are also complex but in theoretical, conceptual, and experimental terms, under the umbrella of medical knowledge). As beforementioned, this is the same symbolic process that takes place in the skin field.

Now, if we pay attention to language, we realize how it communicates the "medicalization" of the body: a blood "sample" is taken, a skin "zone" is photographed; they become parts of the body delimited by the syringe and the camera. Both actors—the physician and the patient—agree, even implicitly, that the medical act will deal with parts.

The whole blood, that is, *my* blood, and the whole skin, my skin, the cover of *my* body, *my* face, *my* identity, have existential meanings, as we have said. Blood as *my* blood is subjectivity: it means *my* life, as it beats and breathes, as well as *my* death.

This makes sense in the life-world, as phenomenology likes to say, but, once in a specific context defined by a place like the hospital, meanings restrict themselves to its rationality, that is, its ways of doing and naming things. Therefore, the existential sense calms down and becomes colder under the laboratory's white lights and low temperatures, the medical office and the medical tasks, and finally, under the focus and *click* of the camera.

In such context, the skin becomes the skin of a patient as long as it gets symbolically detached from the Person and turns into an object of diagnose and treatment in the hands and under the professional sight of the doctor. This detachment is perceptible when gloves, tweezers, and cameras come to deal with a damaged or ill part of the skin, making clear that the physician keeps the distance and relates to parts, as required by the frame of cognitive-instrumental rationality.

However, subjectivity does not mute completely: as long as the patient should give permission to be photographed—even when it is expected almost an automatic authorization—the patient withholds some power, and exercises it; even softly and quietly, she/he points out some conditions, expresses doubts, preferences. Many of them said: "I am not sure that I will authorize the photograph" … "if the physician who takes the photo is not my doctor"; or "if it is my face to be photographed"; or "if my genitals are to be exposed to the camera and to the sight of others."

In such actions, the patients insert what we call "wedges of subjectivity," of what they care—existentially—beyond the objectification of their skin, of their bodies. Affections enter the scene to express and protect the whole person. We can say they are subjectivity gestures because they are filled with sentiments, with issues that *touches* the self.

The person who explicitly prefers that "my doctor takes the photo" and is not sure to give permission to another professional, bases such doubt on a sentiment of trust, as the same patients affirm. It is an affective mediator that leads to give themselves to another person, whom they believe is acting for the sake of their health.

Just a note to say that 96% of the patients in the referred research "agree to be photographed (but) by my physician." The percentage of agreement descends significantly if it is another physician (66%) or a nurse (65%) the one that would take the photo.

Also, agreement lowers significantly to 78% if it is "my face" to be photographed. Here, another sentiment comes to play and introduces doubts: my sense of identity, concreted in my face and in consequence, in my name. "I do not want to be recognized" the patients say.

Doubts are even higher (30% of the patients) when genitals are the parts to be photographed. Now embarrassment is the one that comes to play: "the protection of my intimacy, the defense of my private body."

Trust, protection of identity, and intimacy cover can be seen as three affective fields (what affects, matters) in which subjectivity or the whole Person comes to play in such medicalized contexts, acting against objectification, detachment and instrumentalization.

Now we focus on the third actor in the context that concerns us, besides the doctor and the patient, the camera, the technological artifact that registers the (*my*) skin and allows its reproduction and publication, that is, that allows *my* skin to be observed and evaluated by others, whom *I* also, more or less implicitly, have given *my* permission for the sake of *my* health.

The act of taking a photo also reduces its meaning as its takes place in the medical context: it is not a photo of *myself*, of *my* face and *my* body, or even the photo that takes away *my* soul, as the first and scared photographed people believed more than a century ago. A photo becomes an objective, medical register, again, under the cognitive-instrumental rationality. Only the ill part of *my* skin will be taken.

It is useful to remember that the "sense of touch"; "to have tact" as symbolic fields, move between the skin and good manners in the sense of paying attention to the other, to its needs and preferences, to its fears; of recognize and answer her/him as a significant otherness. Therefore, we would like to emphasize the importance of the tact and the contact between doctor and patient, tact, and contact that have a central role in constructing, building, and nurturing trust, the sentiment of giving myself to the doctor, to put my health, even my life, in her/his hands.

Now, we borrow from Literature an opposite disposition, embodied in Lenz, the soulless character described by Tavares as follows:

> "Lenz was fascinated by that stupid neutrality of the skeleton, that objective rawness of the radiography that led to an invisible democracy far away of the sensations that a normal portrait—a photography for example—could proportionate. All that skulls would have for sure, a singular face" [8].

6.2 The Meaning of Photography

Photographs offer a way to create images, but they also create a representation which involves discourses of truth, accuracy, and realism [9]. What seems to be a positive aspect for the doctor can be a disadvantage from the patient's perspective. Knowing that your weakness or disability will be accurately reproduced and preserved as testimony can be unsettling. Even a baby poses and smiles for a photograph. But a medical portrait, at least under modern standards, has defined posing that does not correspond to aesthetic standards. That representation in illness is just the type of image a person does not want to see of him/herself, much less preserve. It is a remainder of a moment of fragility, of loss of health. In the semiotic of photography, *denotation* is what it is actually seen in the picture. The *connotation* is the additional meaning the viewer adds to the image [10]. For a photograph of a tumor in the skin, a doctor might simply see the represented tumor. For the patient, it can represent a moment when he feared for his life.

6.3 Shooting a Patient: The Camera as a Predatory Weapon

By the end of 2017, Fundación Caixa Forum Barcelona presented an exhibition called "H(a) unting images: Anatomy of a shoot," commissioned to Arola Valls and Ada Sbriccoli [11]. The exhibitions presented a critical analysis of the relationship between the camera and a firearm inviting the audience to make a reflection on the predatory nature of the process of capturing the image. Not in vain, *shooting* is a verb that can be used both for firearms as for cameras.

Throughout the development of the photographic medium, the relationship between the camera and a firearm has expanded beyond the purely technological dimension of the device. Just as firearms have a paralyzing effect on the pointed subject, cameras act in a similar manner. In the exhibition, some of the work by Étienne-Jules Marey (1830–1904) was presented. Marey was a French physiologist obsessed with the study of movement. In 1882 he invented a photographic gun that could take 12 photographs a second recording them in the same frame. He named it chronophotography. His device: a camera similar to a rifle with barrel and trigger.

With the picture, the photographer is in possession of a part of that person. To have a photograph of a patient is to hold power. Doctors become owners of some of the intimacy of the patient. And patients know it. Susan Sontag, in her book *On Photography* wrote: "Photographs really are experience captured, and the camera is the ideal arm of consciousness in its acquisitive mood. To photograph is to appropriate the thing photographed. It means putting oneself into a certain relation to the world that feels like knowledge—and, therefore, like power" [12].

Photographing is intimidating for the subject. To take a photograph is to "participate in another person's mortality, vulnerability, mutability" [12]. The predatory attempt to appropriate another person's reality seems to be part of the nature of photography. Pointing at a person with a gun or with a camera without warning generates a common instinctive reaction: startlement. The patient needs to be aware that he will be photographed and understand the need for the image.

6.4 Photography and Voyeurism

The number of pictures taken daily of patients is enormous. The control over them is still insufficient. Many images get into the website and are viewed by lay people. Old medical photographs have even been used to recreate characters in popular video games [13]. Doctors have photographed the deviant, bizarre, and rare since the beginning of photography and lay people watch at these pictures with morbidity, with the inner satisfaction that the bizarre and sick person in the picture is not themselves. A medical photograph dehumanizes the subject. One such example is found in Diane Arbus´ photographs of people with mental disabilities or physical abnormalities have been criticized as voyeurism [14].

6.5 Conclusions

Very little has been written on how patients feel when photographed for medical purposes. Most is based on questionnaires that indicate that patients usually accept to be photographed as long as they understand what the image will be used for. This requires a clear understanding from the physician's view on the need of the photography. The photographer should be able to transmit the benefit of taking such image as they are sometimes taken to benefit somebody else: a collection, an institution, a physician or medical group (advertisement photography, education/academic or publications). These uses need to be clearly stated as patients can be willing to have their image shared for one use but not for another. In general, there is a clear preference for cameras that belong to the institution, non-identifiable formats, and non-sensitive areas [15–17].

There exists, however, more complex psychosocial and cultural aspects that need further studies. A photograph is an image and as such it generates its own semiotic, a mean of communication and diverse perspectives from the photographer and photographed subject. We need to better understand how a medical image can be "read" both from the patient, doctor, and third parties (medical and non-medical) and what *shooting* means to subject and object.

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7

Doctors as Subjects: Medical Photography as Personal Branding

Fernando Alfageme and Paola Pasquali

Contents

7.1 Introduction

Medicine has been used from the beginning to represent itself by making its professional image into a public one [1]. A portrait is a sign that has served basically two purposes: the description of an individual and the inscription of social identity [2]. Portraits were used to memorialize and to confer status. Its use dates way back to the pre-photographic era.

With the advent of photography, one of the commonest uses of the camera was to produce portraits of doctors. Photography had a distinct democratic potential to make portraits available to almost everybody. And yet, photographic portraits were also used to obtain moral benefit form viewing the social elite [3]. This is where physician's portraits fitted in: photographic portraits were taken as part of the representations of the "great and good." By 1854, photographer André Adolphe Eugène Disdéri patented in Paris what became to be known as the *carte de visite*, an album paper colloid print that could be produced at low cost and in great numbers [4]. Physicians used them to exchange in congresses, send to colleagues and clients, and even sell them once a certain reputation had been achieved [1].

A portrait is more than an image. It represents power. It positions a professional in front of his potential clients, patients, or colleagues. It is the

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presentation, card—the *carte de visite*—that reinforces reputation. A simple mugshot will not do the job. A good portrait is a fundamental part of physician personal branding.

7.2 Essential Personal Branding Concepts for Physicians and Why Personal Photograph Matters

The personal brand can be defined as the fact of considering the person as a product in itself, in the manner of a commercial brand. The term appeared for the first time in an article by Tom Peter called "The brand called you" in *Fast Company* magazine in August 1997 [5] where it was stated that the way to differentiate ourselves in an increasingly competitive world is by managing our career the same way big companies handle their brand products.

Another well-known definition of a later date is the one given by Jeff Bezos, Amazon's CEO, for which the personal brand is "what other people say about you when you're not in the room." That is to say what is perceived of you, regardless of what you say you are.

As a doctor, the goal should be than the patient or colleague could identify you as soon as they see you, to recognize your brand, and choose your service and not someone else's. Today visibility is just as important as education and training. To build it, you will have to focus your efforts on standing out against competitors, being constant and having patience. One of the strengths of recognition will be specialization, which makes you unique.

Find the best version and definition of you, based on history, training, services, and values. It will also be useful to analyze the competition and your professional references to create your own objectives and define the message and the tone in which you want to transmit it. Create the digital strategy and that is where the channels, elements and tools that you will use come into play, always bearing in mind that the personal brand must be flexible and adaptable, so that it grows with you.

Some of the resources to get your brand message transmitted will be elements such as storytelling or pitching, which can be carried out through the text, the word or the image, and its projection in social networks or networking, going to events with your business card or *carte de visite.*

7.2.1 Branding Photography

One of the most important elements to consolidate your brand will be branding photography, which projects your image as a professional, an image that helps to transmit the brand in the best possible way, and a clean image that makes potential customers wants to know more about the services you offer. It is convenient to have a good photographic reserve to help you build your brand.

In addition to the style that best represents you as a professional, you must also take into account other factors such as which platform you use the most to attract your customers, since you will have to adapt to the visual characteristics of that platform.

We will have to think about everything related to that brand perception before the photographic session: logo, identifying colors, content, and value generated to be perceived as a source of trust.

On a personal level, it is important to work before with the insecurity that the photo shoot can create if you are not used to the spotlight, although a professional photographer will help you. The idea is that when it before you sit in front of the camera, you need to feel unique and different, which sometimes requires effort and hours of work, but it is necessary to be able to transmit it these feelings to the camera. Professional portrait photographers have their own system to capture great images: some spend time with the subject to get to know more about him/her; others wait and shoot when they feel they got the right expression or mood.

7.3 Photographic and Composition Features of a Professional Headshot for Physicians

The digital identity is more than choosing a photo for our profiles on social networks or an image for the avatar or a creative photo. It really entails choosing the tone and style that we are going to communicate [6].

It is convenient to have notions of photography and composition to be able to choose between different elements depending on the characteristics of your personality and professional style for the day of the photo shoot, so that the result is what you are looking for.

That image that you want to project is the one that should be clear before doing the session. Do you want to look like a doctor-executive? Or maybe more casual and close? It will be necessary for the photographer to know what you want to transmit with your image and adapt it to the shooting. The goal is to show the personality and make a difference with your competitors.

Some of those basic notions are:

- Composition of the photograph. It is important to understand and decide how to order the image before hands. This will relate directly to what to want to transmit. Diagonal lines create dynamism and movement; vertical lines have the ability to convey a variety of different moods in a photograph ranging from power and strength [7]; horizontal lines convey stability [8] and firmness.
- Apply the rule of thirds [9] to segments the plane into three spaces according to the predominant elements and areas to highlight. Broadly speaking, it consists of mentally dividing the photographic area into three equal parts and placing the objects of interest at the intersections of those lines to achieve balanced and attractive images.
- Use of neutral colors. As a doctor, for example, you can use green and blue traditionally related to relaxing and health.
- Use in the photographs tools of the specialty or daily use in the profession.
- If you want to convey clarity and simplicity, you should not forget that "less is more," a simple and clean image is essential to avoid distractions of the protagonist elements.
- Use of a frontal point in the headshot transmits closeness and trust.
- Take care of the postural language; avoid forced or unnatural postures. The portrait should not seem forced.
- Use a uniform and diffuse light, avoiding dark shadows that create contrast.
- Use the natural lines, symmetry, and framing to give consistency to the composition. This is also very useful for capturing images of surgeries, colleagues, or patients.

The composition, details, and photographic structure that you choose should be able to speak to your audience through the image.

7.4 Errors to Avoid in Headshots and Other Personal Photographs in Medicine

There are some common errors that are usually made in personal brand photographs. They can be done before, during, and in post-production. A check list can help avoid some of these and make your photographic session more productive:

- *Prepare for the session*. Have your hair adequately brush or cut: go to your barber or hairdresser before the session. Have your hair (head, beard, mustache) cut, dyed, and brushed as you want it to appear in the picture. Decide ahead of time what you want to wear including an impeccable and sparkling gown. Bring your favorite make up with you. For your cloths, solid colors work best than patterns; solid subtle color ties are preferred. Do not change your style for the photo. You should look natural and comfortable. When a person meets you after having seen your picture, it should not feel that he is meeting somebody else!
- *Get to the session ahead of your scheduled time.* In addition to delaying the work, the

result will seem not natural if you are not focused and with clear ideas. It will pay off to spend some time with the photographer and open up to let him/her know what you want to convey with your image. By getting to the studio on time, you will have time to prepare for the session: relax, drink something, put on some new and fresh make up; clean up any sweat, brush your hair; adjust your cloth; and make sure every aspect is in place. Prepare a "clean" image by removing excess make-up (use only natural look make up) and oversized jewelry. If you arrive on a hot day, running after doing many errons, or simply have a tendency to get redness in your face, then you might need some time before your skin color adjusts to the new temperature in the photographic studio.

- *Give importance to the background.* The photographer will have to consider all the elements of the space and direct the look to the protagonist object, in this case, yourself. It is important to remove or minimizing the background through strategies such as opening the diaphragm to create blurring or using smooth or light colored backgrounds. Bokeh portraits with illuminated backgrounds are very effective for portraying medical personnel. Shallow depth of field (not in excess because you want the subject completely in focus while the background out of focus) together with a correct contrast and white balance (avoid over-saturated images), softness, and proper shadow transition.
- *Give importance to colors*. They are a very important compositional element and can do to win (or lose) strength to photography. Light colors are usually preferred for closeup shots.
- *Pay attention to the rules of composition*, such as rule of thirds, to get the points of greatest attraction. Unless the breaking of the rules is deliberate to create an artistic effect, you better not ignore it. Many professional photographers use light behind the subject or both behind and in front. The latter stands out the subject and the final image neat and sharp.
- *Use non-conventional head shots.* In some headshots, it may be useful for attention in the center of the facial features or striking aspects of the face. Cutting the top of the head can center your attention on the eyes or a facial expression and remove attention from the hair.
- *Check out on details*. Leave only relevant details, a stethoscope and a dermoscope and remove anything that it is not important. Concentrate on what you want to convey.
- *Focus the image*. For medical branding, a focus image of the subject (you) is fundamental. The eyes are the center of the attention.
- *Posture***.** The general recommendation is to place your back straight but in a comfortable position; some have their photos taken sitting down (usually senior doctors); younger doctors and surgeons tend to prefer stand up images. For doctor's portraits, arms are sometimes placed crossed or with their hands in the gown's pockets—a posture unacceptable in other professions. Posture conventions differ from one profession to another.
- *Smile.* There is an almost universal agreement on smiling for a professional photo. It will make you look more accessible, friendlier, closest, and warmth.

Once you get a photograph of yourself that satisfies your expectations and meets the requirements of an effective branding image, stick to it. Keep it as *the* image to present you. Avoid the temptation of using several images as it might generate confusion. You want your brand to be identified by one image.

Professional photographs can have different uses, and therefore there are different types [10]:

(a) **Editorial portrait**: is taken in your place of work. If you are a surgeon, it will be in surgeon's gown; for ER doctors, within the emergency room; pathologists will have in their labs, with a microscope. The photograph is used in advertising, webpages, and magazines. There are no set rules, but these photos tend to be ¾ portrait or full body portrait.

(b) **Professional headshots**: are mostly done in studio, with certain lighting and background conditions. They usually are head and shoulder portrait (includes upper part of the chest). They are frontal view (mostly for CV) or slightly lateralized.

7.5 Conclusions

Based on what is described in these pages, we can understand the importance of your personal image when building the personal brand. It is about creating a positive message that transmits, that supports, the digital strategy that you will have previously elaborated, being one of the ways in which you will address your audience.

Doctors with profile photos are viewed twice as often as doctors without one and earn 8% more the camera-shy counterparts. Employers are 21% more likely to view candidates with profile photos [6]. The transformation of the current economy makes us in the need to attract more customers. We need to know how to do it. It is about attracting users through the senses, rather than offering a specific service or product. Within this strategy, the personal image is very important, because through it you will create the confidence necessary to choose you and not someone else. That personal brand image should not be spontaneous, it has to be worked and reinforced according to the objectives set in your digital strategy. Enhancing your image will make you a reference. When searching for a service, people will look at that image before looking at anything else. The new business card is a headshot. That image will need to say more of you than any written side information. A picture is worth a thousand words because an image is a complex of connotative symbols that give rise to interpretations. It is your ability and your photographer's to "encrypt" information in that portrait (professionalism, warmth, security, power, respect, competence, and friendliness) that can be later be unraveled by your patients, clients and colleagues.

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Part III

Color in Medical Photography

8 Understanding Color

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and Josep Malvehy

Contents

8.1 Introduction

The applications of medical photography are diverse and can include assisting diagnosis of a disease, monitoring of a treatment, and creating documentation for academic or research purposes, among others. Hence, capturing pictures in a consistent manner with appropriate color management is crucial in clinical photography. Since many medical specialties are mostly visual in practice (e.g., dermatology, plastic surgery, pediatrics, ophthalmology), it seems intuitive that image acquisition should also take into account a standardized management of color. Unfortunately, the practitioners (nurses, doctors, technical professionals, etc.) are not trained in taking pictures in a standardized manner, and they typically are

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not aware of the complete chain of actions that occur from image acquisition until image display, which can result in poor-quality images with inconsistent color characteristics. This becomes all the more relevant with the advent of telemedicine, which needs standardized mechanisms to acquire, store, transfer, and display images. However, for most specialties such standards on color management do not exist. For example, in the case of general medicine, dermatology, pediatrics, or plastic surgery, clinical pictures are generally obtained with a consumer camera or sometimes a smartphone, which can be different from one appointment to another. In addition, even when the same camera is used, color variations can occur due to different camera settings (i.e., white balance, gamma correction, etc.), the image format (i.e., JPEG, RAW, etc.), and its use of full versus indexed color, external illumination, focal distance, and display, among others. This may result in significant variability in color characteristics, making comparisons challenging and potentially misleading, especially as it relates to diagnosis and patient management. In addition, color is particularly challenging since its perception may differ from individual to individual.

In this chapter, we will review the aspects of color in clinical photography that may be relevant for the medical photographer and the user (doctors, nurses, technical professionals, patients, etc.). In order to better understand the complexity of color management and how to handle it properly, we will review how color is formed, interpreted, acquired, and managed in the current digital era; what the current state of the art is; and what the future direction of color in clinical photography could be. Information regarding camera and color calibration will be discussed in a separate chapter.

8.2 Relevance of Color in Clinical Photography, Color Formation, and Color Perception

Color is crucial in clinical photography since small changes in color can affect diagnosis or can determine whether a disease is active (e.g., bright redness in acute eczema) or resolved (e.g., brown hue in resolved eczema). This is especially important in early skin cancer detection when using a dermatoscope (a handheld microscope which can be attached to a camera). Since dermoscopy allows the visualization of structures and colors not visible to the naked eye, color is a fundamental aspect of most dermoscopic diagnostic algorithms [1–3]. However, it is also true that the way humans describe color can be subjective and can vary from one individual to another. These differences in color perception can exist not only due to anatomical variations on the retina but also due to differences during the color formation process.

Humans can identify thousands of colors but generally classify colors into broad categories, using terms such as red, green, yellow, or blue. This differs from the way color is described from a physical standpoint. Physically, color is the result of the reflection of an object illuminated with light from various wavelengths within the visible range of the electromagnetic spectrum, around 400–700 nm. Hence, if no light is reflected (if no illumination is used or if all light is absorbed), the object appears black, whereas if all wavelengths are reflected back, the object appears white. Thus, color depends both on the combination of different wavelengths and on how the eye perceives those wavelengths.

When it comes to the physiology of the human eye, the retina has three types of cones (Fig. 8.1) which absorb light at different wavelengths:

- L cones, which absorb long wavelengths (560 nm) and correspond approximately to “red” color
- M cones, which absorb medium wavelengths (530 nm) and correspond approximately to “green” color
- S cones, which absorb short wavelengths (430 nm) and correspond approximately to “blue” color

The combination of information received in the cones is transferred through the optical nerve to the visual cortex of the brain where it is processed to generate the perception of color. There, neurons may respond differently to certain parts of the visual spectrum, which also depends on the

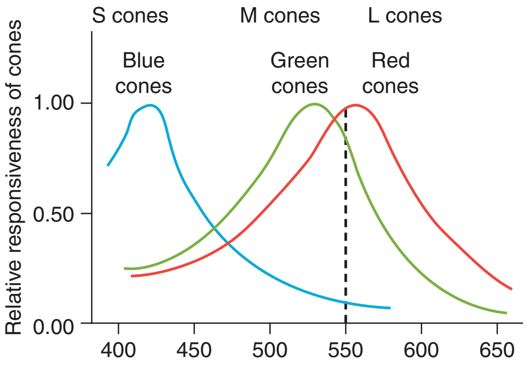

Fig. 8.1 Relative responsiveness of cones. (Image available at: https://i.stack.imgur.com/fNRcL.jpg)

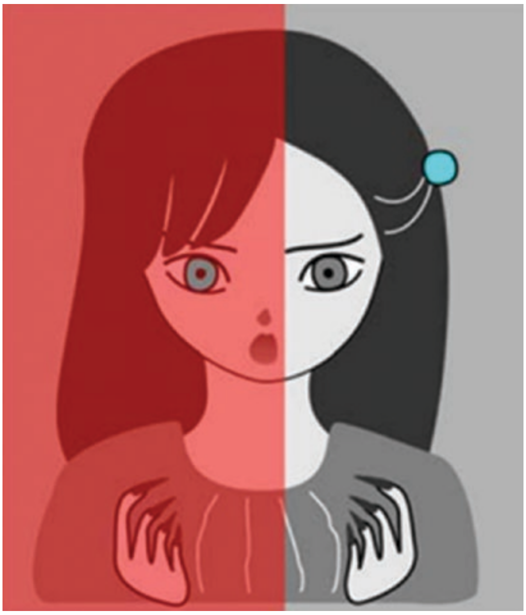

Fig. 8.2 Examples of color constancy. In this image, the color of the right eye is the same as the left eye (gray). However, due to the application of a superimposed filter, the color of the left eye appears blue. This example helps understand why some lesions may look blue on the skin. (Adapted from http://www.psy.ritsumei.ac.jp/~akitaoka/)

adaptation state of the visual system. Thus, a given cell in the visual cortex may respond to all wavelengths under dim light, but may only respond to the red band of the spectrum under brighter light [4, 5]. This may explain why the same color displayed using the same monitor may be perceived differently depending on the illumination conditions of the room, a crucial point in medicine.

Other factors that can influence the brain's response (and therefore, color perception) include anatomical variations [6] and even the colors surrounding the object. It has been proven that the perception of color depends, to a great degree, on the context in which the perceived object is presented, as well as the adaptation state of the visual system [7]. The brain perceives known objects with a consistent color regardless of the amount or combination of light wavelengths reflected by the object. This phenomenon ensures that the perceived color of objects remains relatively constant under varying illumination conditions and is known as **color constancy** [7, 8]. This subjective constancy can often be useful in some situations, such as when comparing two images taken at different time points but with different color profiles. However, this assumption of unchanging colors can also lead to incorrect perception of the true colors if they actually change. One example of the effect of surrounding colors is the perception of blue color on the skin. It has been generally believed that blue color seen in the skin, such as in veins or blue nevi, is caused by the Tyndall effect. However, there is some evidence that the appearance of blue in these skin structures is not because of preferential scattering of blue wavelengths, but is instead caused by a decrease in the reflectance of red wavelengths, which creates an appearance of blue to the human eye when found amidst the surrounding red skin (Fig. 8.2) [9]. Examples such as this illustrate the complexity of the human visual system and how important it is to obtain images with standardized color parameters in order to minimize the impact of distractors and potential subjective color interpretations. Hence, in order to standardize the color parameters in clinical medicine, it is necessary to know the technical factors that influence the imaging chain in clinical photography.

8.3 The Imaging Chain

The sequence of events that occur from the moment the image is acquired until the moment the image is interpreted by a viewer is known as the imaging chain. Several elements form this imaging chain, including a light source, an object to be imaged, a device that captures the image, a device that processes and stores the image, a system that displays the image, and an individual, or computer, that interprets the image [10].

The imaging chain starts with the **illumination** of the object with either natural light or artificial light. Although it has been classically stated that sunlight is the best light to explore the body, natural light can change throughout the seasons or even during the day. Therefore, some suggest that artificial light with a known color temperature similar to natural light (5000–6500 K) may be ideal [11, 12]. When using artificial light, especially regular flash lights without diffusors, care must be taken to avoid shadows and provide homogenous illumination [13]. To compare images over time, it is necessary to obtain consistent, even illumination on a scene while maintaining the same illumination conditions at subsequent time points (Fig. 8.3).

For this reason, some medical devices, such as dermatoscopes, already use predefined illumination. For skin surface imaging, a broad-band white light source with homogeneous illumination seems to be the best illuminant for true and consistent color capture. Since a standard D65 illumination corresponds to midday light in Western-Northern Europe, it would be recommended for skin surface imaging [14].

Typical dermatoscopes have two modes of illumination, non-polarized and cross-polarized, to view or capture skin surface and subsurface information. The non-polarized mode is used for evaluating topographical and textural character-

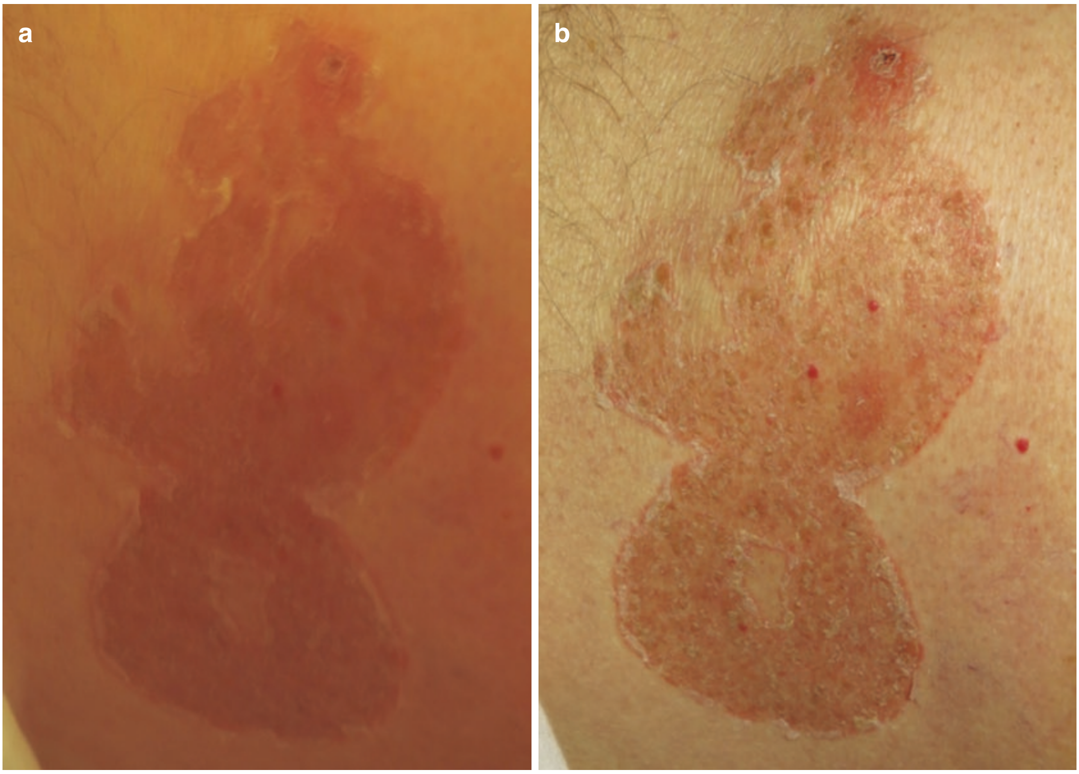

Fig. 8.3 Impact of illumination on clinical photography. Picture (**a**) was taken at f/5.6, 1s without flash, whereas picture (**b**) was taken at f/5.6, 1/60s with flash light. Note that the color tone is more vivid in the picture using flash light, better showing the details of this example of tinea corporis. Even, constant illumination is key, especially to monitor conditions that may change over time and where color is crucial to determine whether the disease is active or cured or to obtain quality images to be transfer through telemedicine platforms

istics of the lesions, while the cross-polarized mode is used for visualizing and differentiating the architecture and distribution of skin pigment (mainly melanin and hemoglobin) for dermoscopic evaluation and classification of skin lesions. Optically, skin is a heterogeneous turbid medium. As governed by the Fresnel equations, approximately 5% of incident light is reflected from the skin surface as specular reflectance [15]. Skin color is therefore mainly determined by diffuse reflection, or the scattering and absorption of incident light inside the skin. The cross-polarized imaging mode captures the diffuse reflectance while blocking the surface reflectance and allows us to visualize the interaction between tissue and light. Absorption of light by skin pigments is color/wavelength dependent. Light scattering and its penetration depth within the skin is also color/wavelength dependent. Therefore, to visualize the distribution of skin pigment and differentiate between melanin and hemoglobin features, the illumination needs to be catered to the light absorption characteristics of these pigments. Between the red, green, and blue color/wavelength bands, red has the most penetration and scattering while blue has the least. Since both melanin and hemoglobin have minimal absorption of red light, this color is of minimal use when visualizing pigment distribution. Melanin absorption of blue color light is very high compared to green, while hemoglobin absorption is high is the green-yellow color band. The absorption spectrums of these two pigments are illustrated in Figure 8.4. Distribution of these two pigments can therefore be best visualized by illuminating the skin using high intensity narrow-band blue color, along with medium intensity broad-band green color, and low intensity red color. Current dermatoscopes therefore provide this illumination using Phosphor-based LEDs.

The next step in the imaging chain involves **image acquisition**. This step is crucial when it comes to color management since many factors in this step can alter color, which includes camera settings (lens, aperture, shutter speed, sensor characteristics) and/or software settings (white balance, image format). Some settings are hardware based, such as the sensor characteristics, which defines the response of the sensor to different wavelengths. Sensor characteristics may vary from manufacturer to manufacturer, resulting in potential color changes when changing

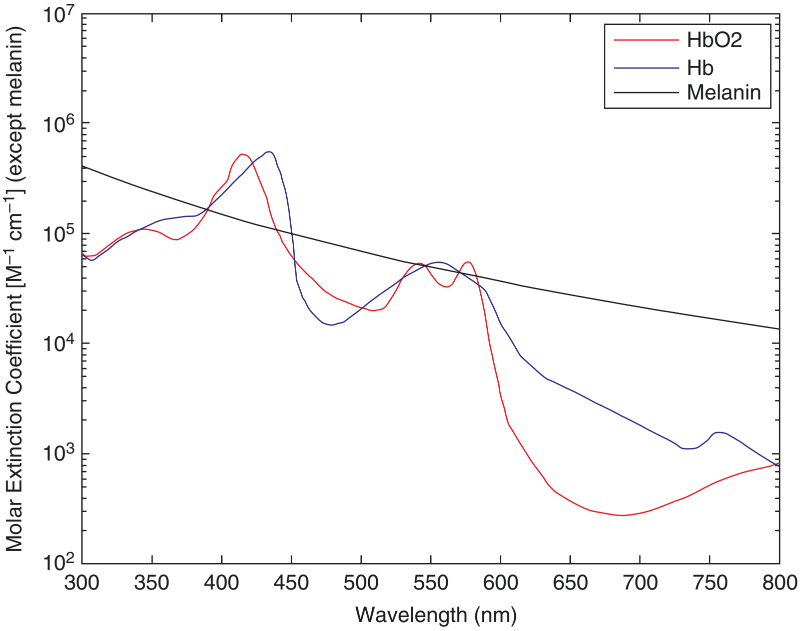

Fig. 8.4 Absorption spectra of Oxyhemoglobin (HbO2), Deoxyhemoglobin (Hb), and Melanin

devices. Other settings such as the white balance are adjusted in software. White balance is perhaps the most important setting since it affects the over color temperature of the image (whether the image appears with a blue, yellow, red, or orange tint), and many cameras adjust this automatically depending on the object being imaged. White balance changes the relationship between the red, green, and blue pixel values, resulting in significant changes in the observed color. In general, some medical devices which obtain pictures in a more standardized fashion such as digital dermatoscopes tend to have predefined settings which minimize the variability between the actual colors in the object of interest and the displayed image. This concept, known as **color accuracy**, defines the transfer mechanisms whereby the input colors are made to match up with the output colors, such as from capture to display [16]. **Color consistency**, on the other hand, refers to the reliability of a system to produce a consistent perceptual response to an observer [16]. Both are important to standardize the color of a system.

The **image format** is one of the parameters involved in image acquisition which describes how the pixel color data in the image is encoded. Multiple formats exist, each with a different goal, but the majority of consumer cameras and medical devices store images in JPEG format [17]. This format has become very popular due to its strong energy compaction characteristics [18] resulting in high compression and its computational efficiency, which has facilitated sharing and storing these images easily. However, unless the capture parameters (white balance, gamma correction, contrast, saturation, etc.) are locked and maintained throughout the use of the imaging device, the color of JPEG images can be manipulated by the camera, possibly changing every time a new image is saved. Additionally, because JPEG images are compressed in a "lossy" manner (indicating that some of the original information captured by the camera is "lost"), the image will contain compression artifacts. Depending on the JPEG compression quality factor, these artifacts can appear as large 8 × 8 pixel blocks. For high-quality levels (low compression), these artifacts are usually not noticeable, but when the quality factor is low (high compression), these artifacts become very apparent. In fact, the visible presence of these artifacts might indicate that the image was saved at a low quality at some point in the image chain, and useful details in the image may have been lost. Formats such as BMP, TIFF, or PNG do not suffer from the lossy compression artifacts that occur with JPEG, but they are also processed with gamma correction, white balance, etc.; hence, they are still susceptible to color variations. Note that resaving a lossy format into a lossless format will not remove compression artifacts; the lossless format will simply save the artifacts as if they were real.

The RAW format, on the other hand, stores the sensor data that the camera has acquired without any in-camera processing. The camera sensor has a mosaic pattern of red, green, and blue filters in front of every pixel element. Thus, each pixel element acquires information of just one color. Typically the in-camera demosaicing algorithm then evaluates the surrounding color values to estimate the missing color information for each pixel element to then form a full-color image. The demosaicing and other in-camera algorithms vary between camera manufacturers, so the same image captured by cameras from two different manufacturers can look completely different. Maintaining the image in the RAW format, on the other hand, allows the user to change the specific set of parameters while keeping the original parameters in which the image was obtained. The advantage of the RAW format is that it preserves the original color bit depth and image quality. Parameters for sharpening, contrast, white balance, and color adjustment can be calculated based on the sensor data instead of an unknown in-camera processing system, and details in shadows and highlights can be preserved which otherwise would have been lost in JPEG-like, 8-bit-per-channel image formats. By using RAW images, one can ensure similar color profile and a reliable baseline for comparing color to other images captured by the same device. Conventionally, the main limitation of using RAW images in digital systems was the file size of each image compared to other formats and the lack of support to capture or display RAW files in many devices. While these issues are less of a barrier nowadays (even many consumer cameras and smartphones are currently capable of acquiring and managing RAW images), the large file size of RAW images still can limit cloud applications (i.e., teledermatology) as well as storage of these files at scale (such as thousands of images stored by a hospital).

Finally, the last step in the imaging color chain involves the image **display** and the ambient light conditions in which the image is visualized. This mostly relies on the monitor characteristics (and whether it can be calibrated), the operating system, graphics card, and most importantly, the ambient illumination conditions. Different brands or models of monitors may have completely different characteristics and settings, which will affect the perception of the displayed images. For example, one's perception of the same clinical image viewed on a monitor in an exam room may be different when viewed later on a monitor in the doctor's office. If these monitors are not standardized and calibrated, the doctor's assessment may differ. Ideally, in order to provide good color consistency, monitors should provide a wide gamut of colors (although most of them are limited in this sense) and should be periodically calibrated. Several devices such as DataColor's Spyder5 [18] exist on the market to measure and calibrate the color output of a monitor. In addition, if pictures need to be compared with high precision, dim light might be preferable in order to minimize the effect of external lighting on color perception.

8.4 Color Measurement, Color Models, Color Management, and Color Profiles

Since color is an attribute of the human visual system, measuring color accuracy involves the use of models that take the perceptual aspects of human color vision into account. Color appearance models try to mathematically describe the shift in color perception as the viewing conditions change.

Based on the human eye receptors (LMS), a color model was developed to include the primary colors perceived by the human eye: the **RGB color model**. In this model, red, green, and blue are individually represented sequentially to produce a gamut of colors. An equal combination of these colors results in white (Fig. 8.5). Nearly all imaging sensors in consumer and medical cameras on the market capture image data in RGB format through the use of individual red, green, and blue sensors tiled across the camera's CCD (charge-coupled device). Likewise, all the image formats discussed earlier encode separate values for R, G, and B. However, without a standard color management for RGB, the meaning of these values is not uniform across different capture and display devices. Consequently, these devices (and image formats besides RAW) in general adhere to the sRGB color space.

The **sRGB** (standard red green blue) color space is an RGB color space standardized by the Commission Internationale d'Éclairage (CIE) as CIE 61966-2-1:1999 [19]. Most browsers, applications, and devices are designed to work with sRGB and assume that the images are in the sRGB color space. The sRGB color space represents the same number of colors as the Adobe RGB color space, but the range of colors that it represents is narrower. Adobe RGB has a wider

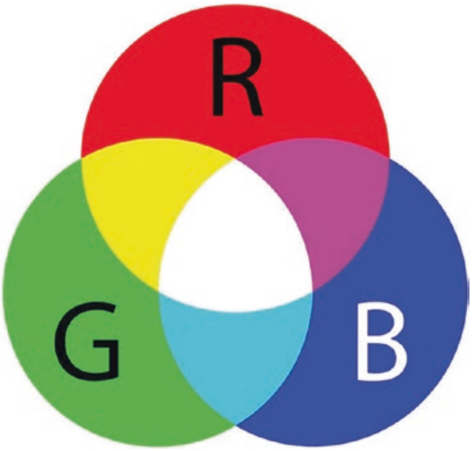

Fig. 8.5 Schematic representation of the RGB color model

range of possible colors, but the difference between individual colors is bigger than in sRGB.

While sRGB is the primary color space that will practically be encountered when dealing with everyday digital images, other color spaces have been developed to better measure color and may be found when dealing with color-based analysis (i.e., the color of a skin lesion). One of these color spaces, the **HSL (or HSV) model**, is a tridimensional model that derives from the Munsell model [20] which evaluates the hue, the saturation (vividness), and the lightness (or value as in the case of HSV) that is encoded in the image. In addition to quantifying the primary colors, this model also measures the color attributes perceived by the human eye/brain system [21].

In 1976, the CIE developed the **CIELAB** color space, or **CIE L*a*b*** or simply **Lab**, to characterize the difference between two colors. This is a tridimensional model that assigns three numerical values to a color: *L* for lightness, *a** for green-red, and *b** for blue-yellow (Fig. 8.6). This color space was constructed such that the Euclidean distance between any two Lab values is proportional to the perceptual difference of those colors to the human eye. This system is based on a previous CIE version, the CIE 1931 XYZ, but has the advantage that this system is device-independent, since it defines a given color by measuring the amount of numerical change in these parameters. CIELAB was originally developed for quality assessment in the print and textile industry, i.e., to avoid the subjective factor in measuring color differences between the color obtained by the printer and the color prescribed by the client. Unfortunately, the response of the human eye is highly dependent on the amount of ambient light (i.e., by increasing the ambient light, the perceived colors become more vivid), and some saturated colors can only be perceived in a given absolute luminance range. Since the CIELAB model does not consider absolute luminance, it is thus adequate for validating colorimetric data (i.e., comparing two colors and quantifying its difference) but ends up ignoring numerous perceptual aspects. To overcome this difficulty, another color space called the **CIECAM02** was subsequently introduced. Unlike the CIELAB, CIECAM02 is a nonlinear color space that takes several perceptual aspects that depend on absolute luminance into consideration. Nevertheless, for most applications, CIELAB is a reasonably sufficient color space to measure and report the color of objects in an image.

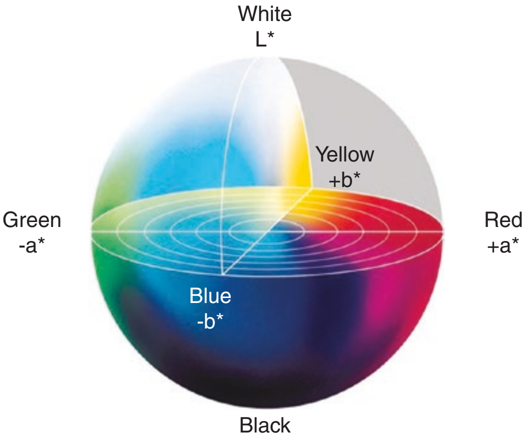

Fig. 8.6 CIELAB color space. In this tridimensional model, *L* defines the lightness of a color, *a** defines the green to red axis, and *b** the blue to yellow axis

Currently, one of the biggest challenges in clinical imaging is the fact that different vendors use different color models in their devices. This makes standardization and comparison challenging. In 1993, the International Color Consortium (**ICC**) was created in order to develop color management standards which would allow uniform color across different software packages and operating systems. Using the CIELAB or CIE XYZ color spaces as profile connection spaces (PCS), the ICC developed color profiles in order to define the color characteristics of a given device and allow color mapping between different systems, for example, color space 1 → PCS (CIELAB or CIEXYZ) → color space 2 [22]. Currently, the ICC has a section which handles the specific situations of medical imaging, called the ICC Medical Imaging Working Group (http://www.color.org/groups/medical/medical_imaging_wg.xalter) which currently works towards the implementation of color management standards in the different fields of medicine. Some medical specialties such as radiology have regulated imaging standards [22], whereas others, such as pathology, are developing color management strategies in order to ensure color consistency and reproducibility [16]. However, most specialties dealing with clinical photography (such as dermatology, wound management, surgery) lack standards on how to handle color.

8.5 Current Color Scenarios

How color is handled differs depending on the needs of different specialties. In general, when we think about clinical photography, we think about the acquisition of images from the skin, but clinical photography also encompasses the acquisition of images coming from areas such as the oral cavity, the gastrointestinal tract, the respiratory tract, or the retina. One could also consider that intraoperative pictures, or even the acquisition of scanned slides in pathology, fall under the umbrella of clinical photography. Some of the situations described in this book chapter deal with color challenges in skin photography where the images are known as “true color.” However, in other fields of medicine, color can be used to annotate, highlight thresholds, as well as artificially color the image (known as pseudo-color). These methods can be used to emphasize areas which are, for example, metabolically more active in cases of PET-CT scans which can be pseudo-colored in red or yellow. Hence, it is obvious that different needs exist in clinical photography. To date, only one consensus paper from the ICC Medical Imaging Working Group has been published regarding some suggestions for clinical photography [16]. Here we will summarize the different color scenarios and describe the ICC recommendations on color management in clinical photography. For more information on these specific scenarios, see chapters included in Part IV.

8.5.1 Skin Photography

In skin photography, only a few studies have looked at color calibration [23, 24] and have developed some recommendations regarding metadata [25] or relevant information needed in teledermatology [26]. Skin photography encompasses different types of images which range from total body photography, close-up photography, multispectral photography, and dermoscopic images [16]. Interestingly, one of the few studies which have assessed the impact of color in dermatology suggested that dermoscopic structures may be more relevant than color when evaluating dermoscopic images and that gray scale pictures may actually be more useful to highlight the dermoscopic structures (Fig. 8.7). However, the authors also acknowledged that colors may be important in select situations [27]. Another important issue is the fact that dermatoscopes can work with polarized or non-polarized light. This leads to the visualization of different structures but also leads to different color profiles. Currently the different devices that store images over time, for example, digital dermatoscopes, do not manage color in the same way and do not address the issues related to polarized or non-polarized light. Most of these devices can result in color changes from one image to another if the device settings are not locked and maintained during image capture (Fig. 8.8). Even though dermatologists have been trained to overcome these challenges, the diagnostic impact of color inconsistency is not fully understood, although it could be more critical in some difficult skin tumors (i.e., featureless, tumors with color variation). The real impact of color in diagnostic accuracy has not been extensively assessed, and prospective studies analyzing the impact of color in the diagnostic accuracy are necessary. In addition, since the color parameters and the acquisition methods are not necessarily uniform, color can be inconsistent depending on how the image is taken. Therefore, it is necessary to teach residents, clinicians, technicians, and nurses the process of capturing pictures in a standardized manner in order to improve color consistency.

Since many devices obtain pictures in a non-standardized manner, it may also be a good option to add color calibration charts (Fig. 8.9) in the field of view while taking the picture to improve color consistency. In this sense, several publications have looked at methods to do so, even in dermoscopic images [24] and in clinical images [28].

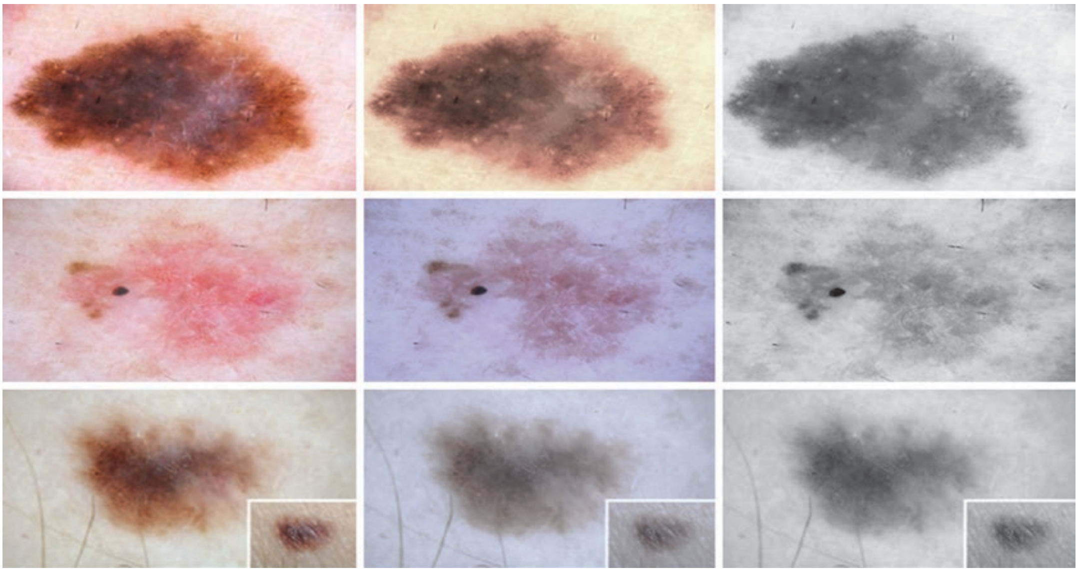

Fig. 8.7 Examples of melanomas showing color variegation. The first column shows images using adjusted white balance, the second one using inadequate white balance, and the third one converting the images to gray scale. It seems that some structures are more conspicuous when using the gray scale mode. However, in very vascular lesions (first row) and in lesions showing scare semiology (second row), color evaluated using adequate color balance seems crucial to identify melanoma-specific structures (in this cases polymorphous vessels and shiny white streaks)

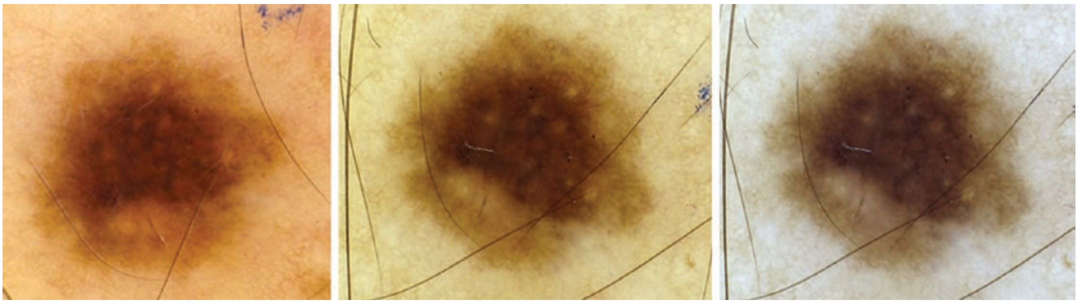

Fig. 8.8 Examples of dermoscopic images taken with the same device over time. While the structures within the lesion remain stable, the color profile changes since the capture settings are dynamically adjusted by the camera software which averages the color in each acquisition. Although the clinical impact of such changes has not been evaluated, it is clear that this lack of color consistency can have an impact when evaluating colored structures

8.5.2 Oral Cavity Photography

Pictures taken from inside the oral cavity face unique challenges when compared to skin photography. Inside the mouth, it is obvious that external lighting needs to be used. In this sense, annular flashlights or fiber-optic lights may be optimal since they produce an even illumination, diminishing the generation of shadows that may occur while using other flashlights (Fig. 8.9). Especially when a dental piece needs to be replaced, it is very important to make sure that the white tones match. Since subtle differences can be very relevant, especially in aesthetic dentistry, standards must be followed to manage color correctly in the pictures used to evaluate such changes. The ICC suggests that clinicians dealing with the oral cavity should know the different color spaces and suggested the use of the DICOM WG 22 (dentistry) color framework to calibrate oral images [16].

Fig. 8.9 Generation of shadows when obtaining images from the oral cavity. Note that there is a shadow in the left upper quadrant of the mouth due to the location of the flashlight in the top part of the camera. This issue can be solved by using annular flashlights

8.5.3 Endoscopy and Laparoscopy

Currently many different endoscopic and laparoscopic devices are used in medicine. In these systems, color accuracy is the most relevant issue to be taken into account, since the clinician needs to see clearly the details and the colors of the cavity being explored live. This concept, of reproducing the details and colors correctly, is known as color reproducibility. Although color is relevant, most clinicians are trained with an individual device and get acclimatized to seeing images under a given color profile. Hence, color consistency among different devices seems less important than in other specialties. However, if a clinician changes, or uses another device, color can be different, requiring additional training. Therefore, standardization among devices may be beneficial, although challenging [16].

8.5.4 Eye Photography

Pictures of the retinal fundus are generally taken to document the status of a patient at a given appointment and also to evaluate changes over time. In this sense, color accuracy is very important to reliably document what the ophthalmologist is seeing, and color constancy is crucial to evaluate changes over time. Similar to skin photography, no standards exist, and therefore, comparison can be difficult. In this sense, the ICC suggested incorporating a color checker when pictures are taken to calibrate the images and to allow adequate color consistency [16].

8.5.5 Pathology Photography

Pathology is currently undergoing a revolution with the advent of whole slide scanning. This allows telepathology and archiving of information in a more efficient manner. However, virtual pathology has very important challenges regarding colors which are caused by (1) different scanners used; (2) different slide processing methods (different staining methods, thickness of slides, etc.); (3) different software packages; (4) different image formats; and (5) different displays. All these factors can generate color variability across different laboratories and sometimes even within a given laboratory. In order to solve this problem, the first step is to generate a consensus between laboratories for how samples should be handled. Afterwards, vendors should agree on calibrating their scanners using the same parameters. Finally, if all of this is not possible or feasible, adequate color management strategies seem the best approach to guarantee color consistency [16].

8.6 Camera Color Calibration

Commercially available systems used in clinical photography nowadays have no adequate color calibration, resulting in important differences in the image that depend on the camera and the computer display utilized by the physician. At this point, adequate color calibration methods can provide improvements on the reproducibility and accuracy of the colors or color-associated structures present in the lesions. In order to calibrate the system formed by the camera and, for example, a dermatoscope, a set of images of a known calibration pattern (i.e., a color checker such as those illustrated in Fig. 8.10) should be acquired. Moreover, the spectral distribution of the light source should also be measured with a spectrophotometer.

Fig. 8.10 Examples of color charts used for color calibration. (Left) X-Rite Munsell Color Checker. (Right) Gretagmacbeth color chart

The calibration provides an estimate of the CIE XYZ values measured by the camera (and dermatoscope) of the colors that appear in the calibration pattern. The accuracy can be measured, for instance, as the CIELAB difference between the known value of a given color and the value estimated by the camera (ΔE). A complex image has numerous spatial visions, local chromatic adaptation, and other effects making it difficult in formulating a simple "color error." For more information on camera color calibration, see the book chapter named "Color Calibration."

8.7 Challenges and Next Steps

Currently, the main challenges regarding color in clinical photography are (1) no color standards exist regarding which color space to use from cameras to displays; (2) different devices use different color profiles and capture settings (often these may be different even for images from the same device); and (3) no study has evaluated the impact of color inconsistency to diagnostic accuracy. In this sense, we believe image acquisition should be performed in a standardized manner in order to obtain the same information over time. This is especially relevant in digital dermoscopic monitoring where factors such as illumination, magnification, resolution, contrast, or display need to be controlled. Calibration methods should be implemented in order to standardize color. Hence, it is crucial to develop strategies to set the foundation to standardize image acquisition in clinical photography as intended by this book. After this step, users and vendors may realize the importance of adequate color management to guarantee color accuracy and color consistency. In addition, collaborative efforts among clinicians, patients, vendors, and engineers are necessary to develop recommendations regarding color management, as well as to perform clinical studies evaluating the impact of color to diagnostic accuracy and the daily practice of medicine. These strategies need to be implemented as soon as possible since teledermatology is a reality that is likely to grow even more with the advent of artificial intelligence algorithms.

Conflicts of Interest The authors do not have conflicts of interest relevant to this publication.

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9

Color Measurement and Calibration in Medical Photography

Elizabeth Allen

Contents

9.1 The Physics of Color

In everyday language humans ascribe certain colors to objects or light sources, for example, "the sky is blue." However, color is not an object attribute but rather an attribute of visual sensation; it cannot exist without an observer which has a means of both detecting and interpreting radiation in the form of color, whether the human visual system or an image capture device.

As described in Chap. 11, the human perception of color arises from the response and interpretation by the human visual system (HVS) to radiation in the visible part of the electromagnetic (EM) spectrum, which ranges between wavelengths of 380 and 720 nm. The EM spectrum extends far beyond that range, and various medical imaging modalities make use of this, including ultraviolet and x-ray radiation at the short wavelength, high-frequency end of the spectrum, and infrared radiation which occupies the region just beyond the long wavelength and low-frequency portion of the visible spectrum. In

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the human observer, the retinal photoreceptors detect the physical stimulus (electromagnetic radiation), and then the neural connections in the visual pathway, and the cognitive system, process and interpret the signals produced by the stimulus [1]. The perception of color is as a result of the integrated response of the three different retinal cone receptors (ρ, γ, β) [2].

The observer is the final component of what is termed the *triangle of color* [3], which describes what happens when emitted light falls upon a surface and is then observed. The first component is a source of visible electromagnetic energy, which will have its own spectral signature. The second component is an object, the chemical and physical properties of which modulate the energy from the source. The final color forms from the combination of all three components of the triangle.

Image capture within an imaging system may be modelled in a similar manner to an observer, replacing the receptors of the visual system with those of the imaging system. Aside from the variability of the colored surface itself, variability in the illuminating light and the color responses of the receptors have an impact on the final color seen or imaged. The color of the object itself therefore cannot be considered in isolation. To further complicate matters, the viewing geometry also affects color appearance.

Visualizing the color triangle as a series of spectral distributions can be useful in understanding how the appearance of a final color is produced. The *spectral power distribution* (SPD) is the relative spectral power output measured at regular increments across the visible spectrum The SPDs of a series of standard light sources are shown in (Fig. 9.1).

The color produced when a surface is illuminated, occurs as a result of the material properties of the surface, selectively absorbing and reflecting (or transmitting) the wavelengths present by different amounts. Because the color produced is a combination of the spectral properties of the illuminant and the surface, and the spectral responsivities of the receptors, it is possible for two different colors to appear to match under some illuminants (see Fig. 9.2). This phenomenon is known as *metamerism*, and it creates complexity in color reproduction and color management but is also the basis for trichromatic matching which allows the appearance of colors to be matched under diverse viewing conditions and with differing white points.

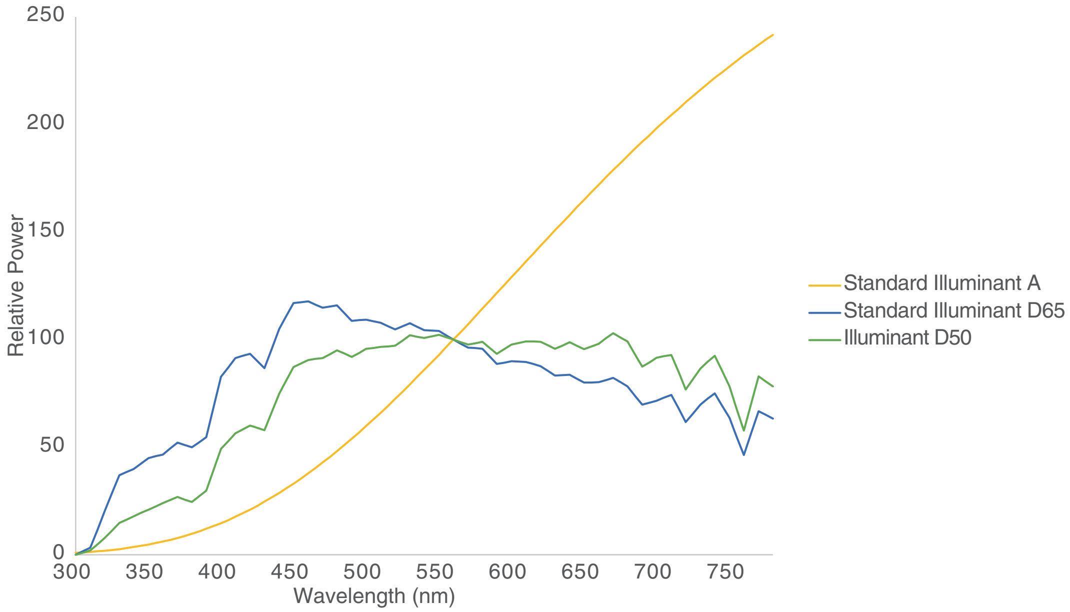

Fig. 9.1 Spectral Power Distributions of Different Illuminants. These SPDs are computed from the CIE data for Standard Illuminant A (to simulate incandescent light sources), Standard Illuminant D65 (simulating mean noon daylight) and Illuminant D50. *Data sourced from CIE 15:2004 Colorimetry standard published by the Commission Internationale de l'Eclairage*

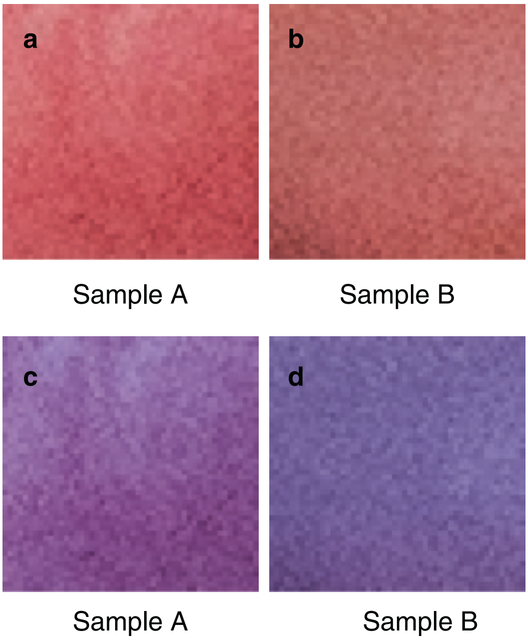

Fig. 9.2 Metamerism. Two equally sized areas from the same image simulating the effects of image capture under an incandescent light source and daylight. The color of the patches is similar under the first illuminant (top row) but shows a more significant hue shift under the second illuminant (bottom row)

9.2 The Appearance of Colors

The color triangle explains what is happening in terms of spectral properties during color capture or viewing, but there are numerous other factors that influence how a color appears, and awareness of these is important in understanding the need for standardization wherever possible, in medical photography and other color critical applications.

As soon as a color is viewed in context, surrounded by other colors, for example, within an image, or on a colored background, or illuminated by a source of a particular spectral quality, or on a glossy instead of a matt paper surface, these environmental conditions will affect color appearance. The human visual system is adept at accounting for changes as a result of viewing conditions [1] and has evolved a number of adaptation mechanisms to assist with object identification and interpretation. One of these is *color constancy*, an adaptation that ensures that the perception of colors remains relatively constant in appearance under changing lighting conditions, for example, when illumination levels change, or under light sources with different spectral characteristics. Human perception of color and particularly perceptual differences between colors are highly influenced by their perceived relationship to white or the light source; hence this mechanism has a significant impact upon color perception. This process is sometimes termed *discounting the illuminant* [3] where the visual system automatically incorporates the white point of the illuminant, effectively shifting the perception of all colors in response to this. Color constancy is believed to be a combination of two effects: *chromatic adaptation* and *memory colors* [3]. Chromatic adaptation may be viewed as a form of automatic white balance, whereby the relative sensitivity of the cone receptors in the eye changes in response to the wavelengths within a light source; for example, under a light source containing more blue wavelengths, such as noon daylight, an increase of the L-cone sensitivity and a decrease in the S-cone sensitivity will ensure that white objects will appear white rather than blue. Memory colors are prototypical colors associated with particular highly recognizable objects; these are individual to the observer, but certain trends are common, for example, grass is typically remembered with more of a green hue than it has [4].

There are other color appearance phenomena that may affect images when viewed separately or on different systems. *Simultaneous contrast* describes the shift in color appearance as a result of the color or tone of the background [5]. Apparent shifts are based upon the opponent theory of color vision, whereby the signals from the three cone receptors are combined to form three opponent signals, red-green, blue-yellow, and light-dark [6]. Simultaneous contrast results in images on a lighter background appearing to be darker; those on a dark background appear lighter, red colors make the colors next to them appear greener and vice versa, and blue colors make colors next to them appear yellower and vice versa. This phenomenon highlights the necessity to control viewing conditions at output; whether viewing on a display or on a print, the background color and lightness will affect the image appearance in terms of color and contrast.

Initial object recognition is generally driven by the spatial and tonal properties of images, fundamentally related to global and local contrast characteristics. The visual system has light and dark adaptation mechanisms to respond to differing illumination levels and is far more sensitive to tonal differences than color differences; once object recognition has occurred, color adaptation mechanisms, as described above, affect color appearance. These mechanisms are important as color evaluation almost always involves comparison of colors, either against another colored object or against a memory object.

The various adaptation mechanisms work well for the human visual system, but without their effects being built into color reproduction of images, they can produce unpredictable results when viewing images produced or viewed under different conditions. Where images are to be reproduced on the same medium for comparison, and the viewing conditions and the white point of the illuminant are the same, color appearance phenomena are less likely to influence the evaluation. But as soon as there is a change in medium (e.g., from display, which is emissive, to print, which is reflective), the contrast characteristics and the white point may potentially change. Additionally, printed images are perceived as illuminated objects, and therefore the visual system discounts the illuminant, whereas this mechanism will not occur with the display, because it is self-luminous, and no known illuminant is present [3]. Essentially different color appearance mechanisms are at work when images are displayed upon different media.

9.3 Color Reproduction in the Digital Imaging Chain

The imaging chain encompasses the devices and encoding of image data from input to output. As described by Triantaphillidou [7], a color space encoding is the digital encoding of a color space, which is an *n*-dimensional coordinate system to specify the position of a color within the space. The color space encoding describes the digital encoding of the underlying continuous color space, for example, the bit depth and quantization, which determines the range of values that may be taken within each color channel. Color spaces may be classified according to the method of color reproduction (additive such as RGB or subtractive such as CMY), whether they are specific to a device and whether they have a defined relationship with human color perception.

In a typical imaging chain, image data may be transformed through a number of different color encodings, as illustrated in (Fig. 9.3), the nature of which are related to the image format, the characteristics of the device, and color management decisions made based upon the color reproduction objectives of the application.

Digital color reproduction requires the transformation of image data values between color models and color spaces in a manner that repro-

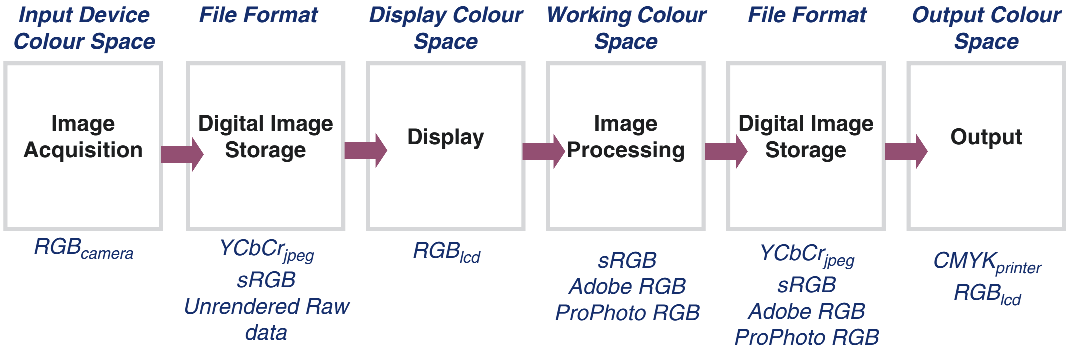

Fig. 9.3 Color through the imaging chain. A typical digital imaging chain, from capture to output, with examples of the possible color spaces that the image may be encoded in to at different stages

duces the appearance of the colors as accurately as possible. The color spaces native to input and output devices are *device-dependent* color spaces; the coordinates used to represent the colors are defined by the nature of the color space, and the color gamut is based upon the characteristics of the device, determined by the following factors:

9.3.1 Spectral Characteristics of the Device Primaries

All digital color devices have a set of primaries, which are the set of colors, which, when mixed in different proportions, will produce other colors. These determine the color channels used to create color and are chosen to produce the widest possible color gamut in a given imaging system. In input and display devices, the primaries are additive RGB, meaning that white is created as an additive combination of the three red, green, and blue primaries at their maximum. In print devices, the color space is subtractive, meaning that the color channels subtract from the reflected illuminant spectrum; white is produced when the color channels are at a minimum.

The primaries in a digital camera are defined by the spectral responsivities of the filtered CCD or CMOS pixels, so they are a result of the sensor sensitivity and the spectral transmissivity of the overlaid RGB filters. In a scanning device, and in other illuminated optical devices, such as dermatoscopes or endoscopes, the primaries are a result of the RGB-filtered sensors and the spectral characteristics of the illuminant. In the latter case, color rendition has also been found to be affected by illumination intensity [8]. Display device primaries are defined by each of the three color channels when at a maximum (e.g., when a pure red pixel is displayed, which in a 24 bit color system will have a value of [255, 0, 0]); in LCD devices, they are defined by the spectral transmission characteristics of the filters overlaying the backlight.

Color printers use a subtractive set of primaries, in the form of dye-based or pigment-based inks in the case of inkjets or dye particles in the case of dye sublimation printers. These may be three channels of cyan, magenta, and yellow or have a fourth black “key” channel (the “k” in CMYK) to improve contrast. The primaries are a function of the spectral reflectance of each individual dye or ink layer at its maximum saturation combined with the spectral reflectance of the underlying substrate (the paper color). When the full saturation of all three- or four-color channels is overlaid, they subtract light to produce black.

9.3.2 White Point

The white point has different characteristics, depending on the type of device and whether it incorporates an illuminating device. The white point in a digital camera is related to the scene conditions, i.e., the spectral qualities of the illuminant, but also the white point that the camera is adapted to, which may be achieved by adjusting the analogue gain of the three channel signals [9] or by post-processing the digital signal during image rendering. The white points of scanners, dermatoscopes, and endoscopes are defined by the spectral characteristics of the unfiltered illuminant. In a display incorporating a backlight, the white point is defined by the spectral characteristics of the backlight when the color filters are completely turned off (meaning that all the light is emitted from the display). The white point of a printer is determined by the white point of illuminating light and the spectral reflectance distribution of the paper.

9.3.3 Transfer Functions

The transfer function is the device tone reproduction function, sometimes called the gamma function; it defines the range of tones and the contrast of the device and the relationship between the input and output intensities. Each color channel has its own transfer function, and these are set during the calibration of the system (e.g., by changing the gamma value during display calibration). A change to one or more of the transfer functions will result in significant color shifts as the relationship between the color channels changes and may result in a color cast within neutral greys.

Device-dependent color spaces are not only variable with the make, model, and spectral characteristics of the primaries of the devices; there can be variability between devices of the same model and in reproduction from the same device over time. The variability may be as a result of different hardware or software settings (e.g., through different white point setting or gain adjustment of individual channels) or as a result of aging of device components (e.g., the change in white point as the backlight source ages) or color drift (e.g., in an inkjet printer a change in the amount of different inks being laid down as a result of print head blockages). A reduction in device variability is one of the purposes of calibration, as described later in this chapter.

A further limitation of device-dependent color spaces is the lack of a defined relationship with the response of the HVS and a lack of perceptual uniformity in terms of color differences.

Device dependence is one of the key issues to be addressed through color management. Early color management was achieved between two devices (e.g., from a scanner to a printer) by measuring the color reproduction of a specific set of colors from the two devices and creating a direct color transform that could be applied on the data from the input device to correctly reproduce the colors on the output device. This *closed loop* color management worked well between two devices but required detailed knowledge of the two devices and an experienced operator to monitor color drift and recalibrate regularly [10]. Such a system may be suitable in a medical photography context, for example, if the images are always to be captured in controlled lighting conditions and always viewed on the same display, without the need for transmission or archiving. But in many contexts, this is an unsatisfactory solution, which relies on unchanging technology and does not future proof the images.

As a result of the growth in the use of true color images in medical imaging, image colors need to be translatable and consistent between multiple different devices, different imaging chains, to different output devices, and, in telemedicine, between different imaging locations. The growth in fields such as teledermatology and telepathology allows access for patients to specialists in distant locations, but poor color translation can impede diagnosis [11]. As in consumer digital imaging, closed loop color management is inadequate for situations with multiple devices, rapidly growing in complexity, and therefore a standardized framework for color reproduction and management is required. The International Color Consortium (ICC) architecture provides this through open loop color management, which uses an intermediate device-independent color space into which all device color spaces can be translated (Fig. 9.4).

The work of the ICC Medical Imaging Working Group [12], introduced in Chap. 11, aims to bring together different working practices from disparate specialisms to define standards and guidelines for color reproduction. Generally, it has been found that color within various clinical specialisms tends to be managed in a rather ad hoc manner. Digital microscopy, telemedicine, medical photography (particularly ophthalmic, dental, and dermatology), and display calibration have been identified as priority areas in which improvements in the consistency and standardization of color reproduction would produce significant and tangible benefits [13]. To date the ICC MIWG have produced a number of white papers, reports, and other resources with recommendations for best practice in different areas, including pathology, medical displays, a color eye model, digital photography, and a range of other areas of interest.

9.4 CIE Colorimetry and CIE Color Spaces

The measurement of color using colorimetry is at the heart of color reproduction and ICC color management. It aims to define color measurements and specifications that directly relate to human color perception. The Commission Internationale d'Eclairage (CIE) approaches to colorimetry and CIE color spaces are device independent, providing absolute color specification and are therefore used as intermedi-

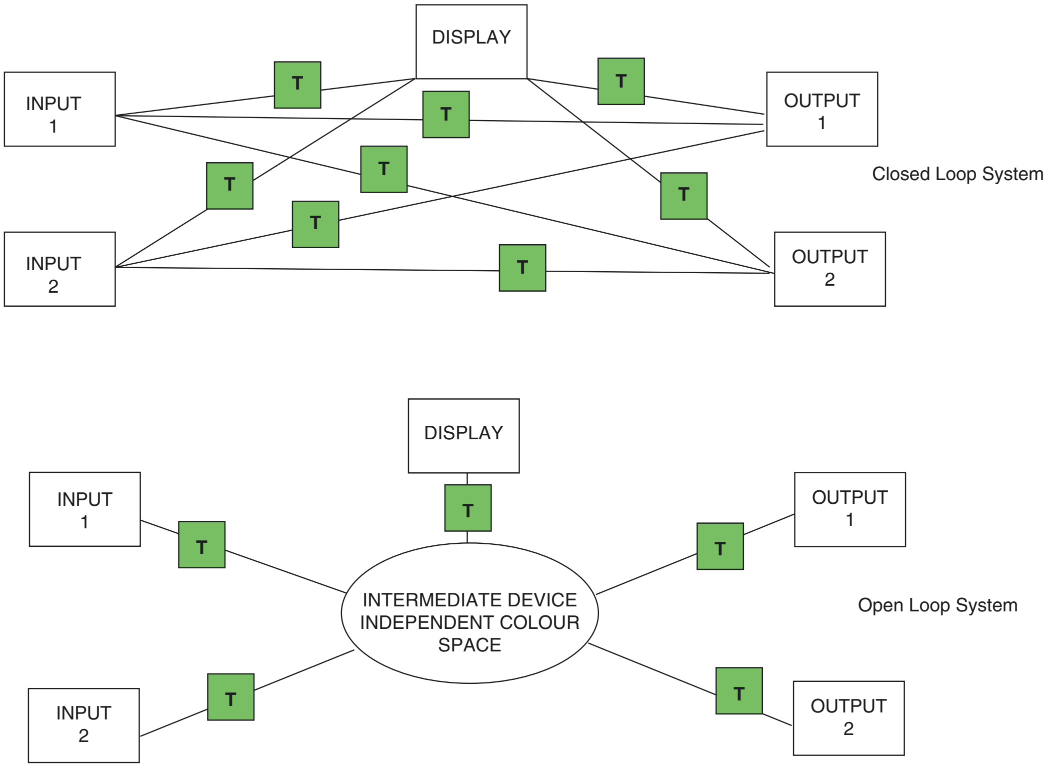

Fig. 9.4 Open loop color management uses a central connecting color space to reduce the required number of color transforms, compared to closed loop color management systems

ate connection spaces in open loop color management.

The CIE model of colorimetry originally derived from a color matching experiment implemented in 1931, in which observers were required to match various colored patches by mixing and changing the amounts of three projected superimposed illuminants of short, medium, and long wavelengths. The experimental data were used to obtain the CIE standard observer color-matching functions, which are the theoretical chromatic responses of the average observer across the visible spectrum. Initially expressed as the combination of responses of three monochromatic lights of wavelengths R = 700 nm, G = 546.1 nm, and B = 435.8 nm, these were mathematically transformed to obtain a set of imaginary primaries *X*, *Y*, and *Z*, which could be combined in different proportions to match all possible perceived colors. The color matching functions for the CIE 1931 2° standard observer [14] are illustrated in (Fig. 9.5). Colorimetry defines colors in terms of the proportion of the three primaries, the *XYZ* tristimulus values [15], and may be measured using a spectrophotometer or more commonly a colorimeter.

The original tristimulus values defined from the 1931 experiment are still used in International Color Consortium (ICC) compliant color management systems. Further experiments confirmed the validity of the data and were extended to obtain a dataset for a 10° viewing angle, the CIE 1964 10° standard colorimetric observer.

The CIE *XYZ* color space is a three-dimensional coordinate system in which all colors may be expressed as a combination of the three coordinates; it also relates to the human visual response, whereby each of the *XYZ* color-matching functions may be considered as a linear combination of the cone responsivities. At the heart of color management is the process of transforming colors in the real world and in

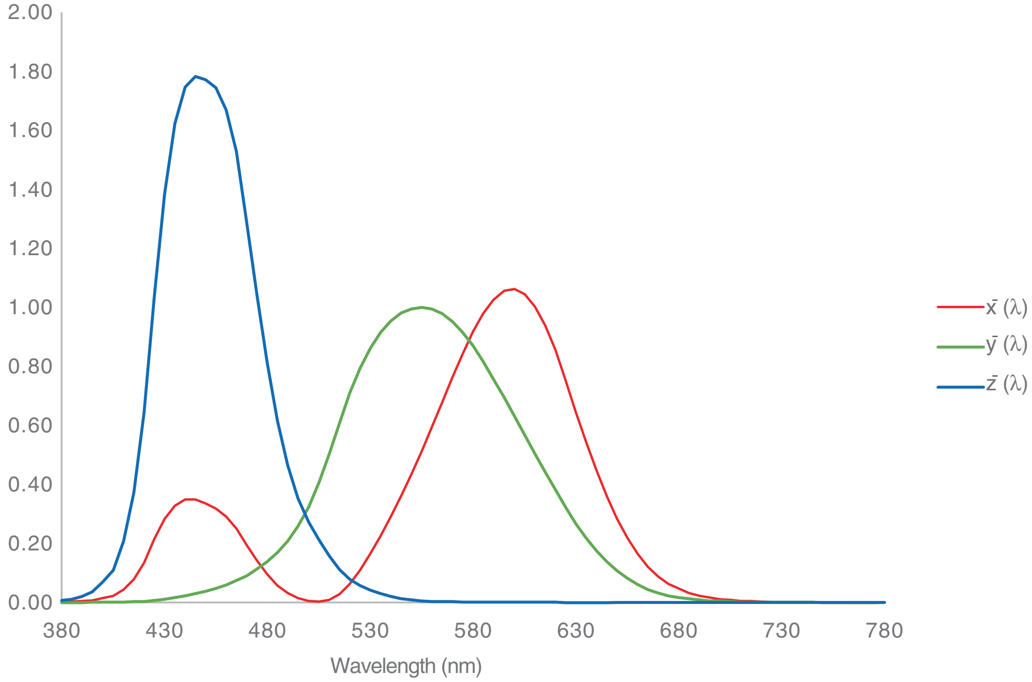

Fig. 9.5 CIE 1931 2° standard observer color matching functions Data sourced from Colorimetry *Part 1: CIE standard colorimetric observers (ISO/CIE 11664-1:2019) published by the Commission Internationale de l'Eclairage*

device-dependent color spaces into colorimetric values. Expressing colors in terms of colorimetric values provides an absolute system of measurement in which colored objects and the white points of illuminants may be mapped, compared, matched, and discriminated in a meaningful manner independently of the devices or media upon which they are reproduced. By doing so, it is possible to transform and reproduce colors on different devices and under different viewing conditions, which will be perceptually as close to the original as possible, within certain defined limits.

The transformations to obtain tristimulus values are designed such that the Y tristimulus value represents the luminance of the color. The XYZ values may be further transformed into chromaticity coordinates as follows [14]:

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z}$$

As x, y, and z are normalized values, only two of them are required to represent a color, and they can therefore be represented on a two-dimensional diagram, which is somewhat easier to understand than a 3D space. An x, y chromaticity diagram provides color information but no luminance information.

The CIE x, y diagram is often used to represent color gamuts of imaging systems for comparison; however this is not without problems, because it is not perceptually uniform, meaning that equal distances between colors in different areas of the chromaticity diagram are unequal in terms of perceived difference. A further transformation of X, Y, Z values in 1976 produced the CIELUV [16] and CIELAB [17] color spaces. These three-dimensional spaces represent colors in terms of lightness and two chromaticity coordinates. The CIE 1976 uniform chromaticity scales diagram, derived from the CIELUV space, represents colors in terms of the u', v' chromaticity coordinates in which the differences are nearly perceptually uniform.

The CIELAB space is used widely in color imaging applications (6,6) and is defined from the XYZ values, incorporating their relationship with the XYZ values of the illuminant white point.

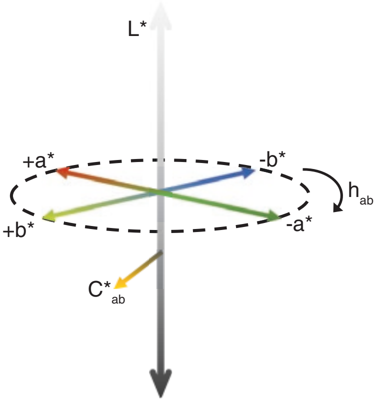

Fig. 9.6 Three-dimensional representation of the CIELAB uniform colour space. The vertical L* axis corresponds to the lightness of a color and the color coordinates a* and b* correspond to redness-greeness and blueness-yellowness respectively. Cylindrical coordinates, C*ab and H*ab are also illustrated; the distance of a color from the central L* axis defines how chromatic it is and the angle around the centre determines the hue

The resulting coordinates L^*, a^*, and b^* correspond to lightness and two color coordinates. The a^* and b^* values define the color on scales which approximate perceptions of red-green (positive a^* to negative a^*) and yellow-blue (positive b^* to negative b^*). From these values, the perceived chroma $C^*_{a,b}$ and perceived hue $H^*_{a,b}$ may be calculated (Fig. 9.6). Defining a color in terms of hue, lightness, and chroma is undoubtedly more intuitive and easier to understand and visualize for the human observer than expressing them as LAB or *XYZ* (or even RGB) values.

9.5 Standard RGB Color Encoding

There are a number of other color spaces that refer to devices, either real or virtual, but with a defined relationship with CIE colorimetric spaces, so that they can be considered to be device independent or device standardized. They are used widely in digital imaging and implemented in imaging software to enable standard color space encoding.

sRGB (standard RGB), introduced in Chap. 11, is one such color space relevant to medical photography. It is an international standard, published by the International Electrotechnical Commission (IEC) [18], and is a type of *output-referred* color space encoding. Output-referred color space encodings are linked to specific real or virtual output devices and viewing conditions [7]. In the case of the sRGB encoding, it is based on typical cathode ray tube (CRT) display primaries and transfer function. Originally developed as a default color encoding for the Internet in 1999, it has found widespread adoption in various imaging industries, including medical photography; if two displays and their viewing conditions are calibrated to the sRGB standard, then the appearance of an image viewed with an sRGB profile on the two systems should be consistent. The standard specifies CIEXYZ tristimulus values for the primaries and the D65 white point, a gamma value of 2.2 and a set of reference viewing conditions in terms of ambient illuminance level, an ambient D50 white point and details also for the background and surround luminance levels.

9.6 Calibration, Characterization, and Color Management

Small changes in color reproduction in medical photography have the potential to significantly impact accurate monitoring of disease and the effectiveness of treatment over time, particularly in color critical applications such as dermatology. This places particular requirements on the system for accuracy and consistency. As stated by Revie and Green [19]: "Many of the current problems in color in medical imaging can be classed as problems of calibration of image capture and display systems" (p. 2). The processes of calibration and characterization are intrinsic to color management. More detail is provided about the characterization of different types of devices later in the chapter; here they are considered more generally.

Calibration is concerned with maintaining consistency and stability within a system, by ensuring that any factors (hardware and software settings, media, viewing environment) that might influence image reproduction remain unchanged and periodically checking and resetting them if they have shifted. Examples include maintaining the system white point in a display or grey balancing a scanner. Selecting the paper and colorant type is part of the calibration of a printer, but color and tone reproduction will vary between batches of both, so printers need recalibrating when a new batch of paper or colorant is installed. The necessary regularity of calibration is dependent upon the device and its susceptibility to drifting away from the calibrated state.

Characterization is a process of measuring the color and tone reproduction of a device and defining the relationship between coordinates in the device-dependent color space and CIE colorimetric coordinates. The output of the characterization process is a device profile; it is produced after the device has been calibrated (although some profiling devices will perform both), and the profile will only be valid and correct for that calibration condition [7], meaning that a change in conditions requires a new profile to be created. Device characterization enables the translation of colors from one color space to another, either directly or via a CIE color space in an ICC framework. An example of the use of profiles in an ICC color managed framework is shown in (Fig. 9.7).

Correctly and regularly calibrated devices, an intermediate colorimetric profile connection color space, and accurate profiles are the building blocks of color management systems. There are two further factors that determine how colors are rendered when transformed from one color space encoding to another in an ICC compliant system.

9.6.1 Gamut Mapping

The gamut of each color space defines the range of possible colors that can be encoded within the space. When transformed into a common colorimetric color space, the color space gamuts occupy different areas and shapes, depending upon the position of their primaries within the space. The three standard RGB color spaces can be illustrated on a chromaticity diagram as shown in (Fig. 9.8).

While there is a significant area of overlap within the center of the gamuts, they have some areas that are unique to each space, and this is a common problem, particularly when transforming from an RGB space of an input or display device to the CMYK space of a printer. There will be some colors in each space that cannot be mapped in an exact way. The process of gamut mapping adjusts the colors of the input image or the input device to fit those of the output device and requires characterized or profiled devices at input and output [7]. In the areas of overlap, colors may be matched, but in areas outside the common area, a decision must be made about what happens with out-of-gamut colors. The approach used within the gamut mapping algorithm depends on the color reproduction objectives. If colorimetric accuracy is paramount, then only the central colors can be correctly reproduced, and the approach is *gamut clipping*, where the colors in the common gamut boundary are unchanged, leaving a few very saturated colors to be clipped to the boundary. In medical imaging applications, this can be a satisfactory approach if these highly saturated colors are not prevalent

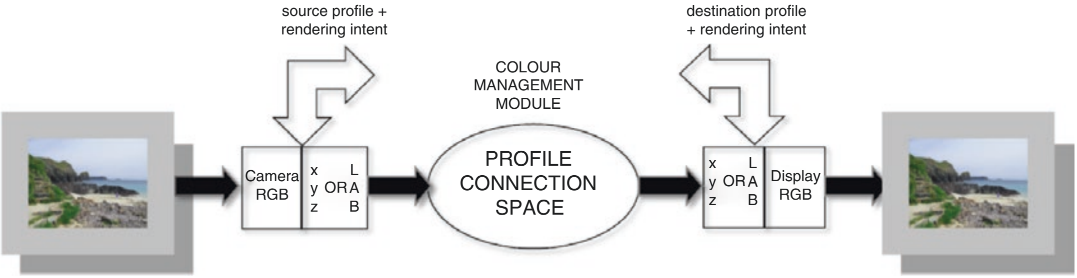

Fig. 9.7 Image capture and viewing in an ICC profiled and color managed system

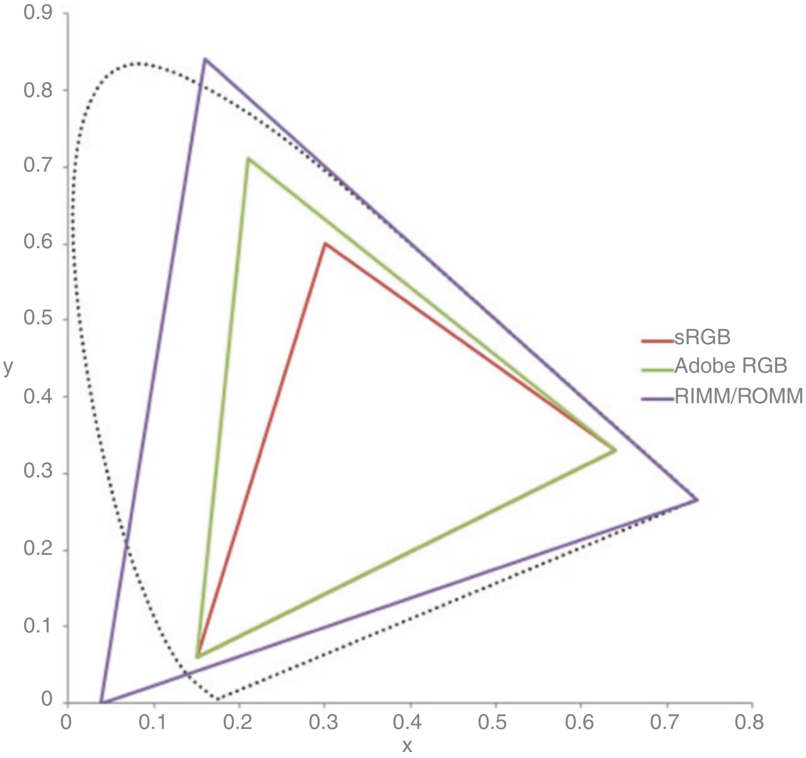

Fig. 9.8 Gamut space comparison of standard RGB color spaces on a CIE x,y chromaticity diagram

so that the color differences in these areas can be ignored. *Gamut compression* mapping algorithms instead compress the entire gamut into a smaller area. In this case, all colors are shifted to become less saturated, but relative color differences are maintained, and the color differences caused by the gamut mismatch are spread across the entire range. In both methods, priority is given to minimizing hue shifts.

9.6.2 Rendering Intents

In ICC color management, the gamut compression method is defined by selecting a *rendering intent* when converting between a source and destination profile. At the time of writing, there are four rendering intents defined within the standard; two of these, the *ICC absolute colorimetric* intent and the *media-relative colorimetric* intent, are suitable for medical photography (the other two are designed to produce pleasing images in more general imaging applications). Both the absolute colorimetric and media-relative intents produce colorimetrically accurate colors, the difference being that in the media-relative intent, the media white point is mapped to the white point of the profile connection space (PCS), whereas in the absolute colorimetric intent it is not. This means that with media-relative rendering, the white point of the image appears white even if it was a yellowish white (this is analogous to chromatic adaptation in the HVS) and all other colors are mapped relative to this white point, meaning that all colors shift. This is more suitable for human visual assessment of images, where images need to be reproduced to be visually accurate. In absolute colorimetric rendering, if the media white point was not the same as the white point of the PCS, it will appear different; a yellowish white point will appear yellowish. In this case, all colors are preserved exactly. This approach is suitable where images are to be evaluated or processed using an image analysis algorithm and absolute colorimetric accuracy is required.

9.7 Camera Calibration and Characterization

As described in Chap. 11, the use of a camera with another device such as a dermatoscope enables the calibration and profiling of the system, in part because the imaging conditions are possible to control, because of the close focusing distance and the use of an illuminating device. In much of medical photography, however, imaging conditions are more variable. The increasing use of mobile devices for image capture, particularly in telemedicine, represents significant challenges in terms of controlling and reducing color errors, which, once introduced at image capture, will be propagated through the entire imaging chain [11]. The quality of cameras ranges from mobile phone cameras, through point and shoot compact cameras, to professional-level DSLRs, and in this range, the level of automation versus the level of manual control is hugely variable; the situation is further compounded by the level of skill required of the camera operator to enable purposeful control of the image in high-end systems. Penczek et al. [11] tested the effect of various imaging conditions upon the color performance of mobile phone, point and shoot, and DSLR cameras and found the most significant errors introduced at capture by position in relation to light source, the type of light source used, and the camera technology. As expected, the overall errors were highest with the mobile phone camera, followed by the point and shoot and then the DSLR. All three cameras performed best under daylight-balanced fluorescent illumination; the DSLR as expected produced the best results, with excellent color rendition of flesh tones under daylight illumination, but performed badly under incandescent and cool white fluorescent illumination. The ICC has developed guidance for improving color in medical photography [20] also highlighting the primary factors that contribute to color error at image capture as lighting uniformity, the spectrum of the lighting, camera technology, and subject color. Poor framing, focus, exposure, and incorrect white balance also have an impact upon color.

Generally, therefore, the best results will be obtained using a professional DSLR, adhering to good practice guidelines for framing, focus, and capturing RAW files to fully utilize the available bit depth and dynamic range of the image sensor (see Chap. 11). If this is not possible, improvements can still be made by optimizing lighting and including a color test chart. Using an illuminant with a spectrum as close as possible to D65 will produce better color rendition regardless of the camera used, and uniform diffuse lighting helps to reduce non-uniformity across the image plane.

To produce calibrated images, an image must be captured of a test target containing a set of known colorimetric values (see examples in Fig. 11.8 of Chap. 11) from which a profile can be constructed that relates the camera RGB values to the colorimetric values of the chart under the same conditions. This can be a challenge in specialisms such as ophthalmology and pathology and is an area being addressed by the ICC MIWG, with the development of a calibration slide for histopathology and a miniaturized color checker chart which can be inserted into a model eye for fundus photography [19].

Images may be captured and rendered in a *scene-referred* or *output-referred* encoding [7, 20]. An output-referred encoding is one that has been optimized for a real or virtual output device, so could be for a printer, or using a color space such as sRGB. The images will be rendered for viewing, and in the case of JPEG files, output rendering is the only option. In such cases some color rendering will be applied automatically to optimize the results for the output color space. This process is proprietary, and so it is difficult to obtain colorimetric values from an output-referred image. Nevertheless, this may be the only option unless using a DSLR. Better results will be obtained if capturing to an uncompressed TIF file, although the images will still be output-referred. In such cases the best option is to capture the image with a color chart or capture the color chart in a separate image under the same lighting conditions, correct any illumination non-uniformity, and gray balance the image using a custom white point correction from the color chart image. A color correction profile or a set of presets for specific conditions can also be created from the color chart image, to be applied to the captured image. It may be possible to retrieve original scene colorimetry if the color rendering method is known.

Scene-referred images are encoded to preserve the original scene colorimetry and may be created within the ICC architecture using two different approaches, either by creating a custom camera profile for the camera illumination or by using a standard scene-referred profile. In both cases the images must be captured as RAW files. The custom camera profile allows direct conversion from camera RGB to colorimetric values in the profile connection space but requires special software to build the profile for the specific camera, settings, lenses, and illumination. Alternatively the images may be converted to a standard scene-referred RGB space; the one recommended by the ICC is the linear_RIMM-RGB_v4.icc profile, which can be downloaded from the ICC website [21]. In general, scene-referred images will produce more consistent results when compared in terms of either colorimetric measurements or viewing over time; it should be noted however that in general, it is not possible to directly view scene-referred image data and therefore the image will finally have to be output referred. This requires that the image is converted to an output-referred encoding; in this case the sRGB standard encoding is recommended, with a media-relative colorimetric rendering intent. It is worth noting however that sRGB has guidelines around viewing conditions which should be adhered to for best results. Adobe RGB 1998 is another standard encoding with a slightly wider gamut, which may be appropriate for soft-proofing images for print.

9.8 Output Device Calibration and Characterization

Both displays and printers are classed as output devices, and therefore the accuracy of their calibration and characterization is important at the stage at which the images are to be viewed by clinicians. However carefully an image has been captured, and the capture system has been calibrated and profiled; an uncalibrated or poorly calibrated output device will result in incorrect rendition of colors (and in the case of printers, typically a loss in image saturation and the potential for color shifts because of the often significant gamut mismatches between RGB and CMYK color spaces). As described earlier, the calibration step in each case requires the setting of conditions prior to profiling, followed by regular recalibration to return the device to those conditions and ensure that the profile remains valid.

9.8.1 Display Calibration and Characterization

There are a number of portable devices available for display calibration and profiling, or in high-end workflows self-calibrating monitors, with built-in calibration tools; most methods will perform the calibration immediately before the characterization, which ensures that the profile matches the conditions. It is important to allow some warm-up time to ensure that the display has stabilized to prevent erroneous results.

The steps required for display calibration involve an initial setting of display black and white point luminance to adjust the dynamic range and overall brightness. The calibration involves setting of a target white point color temperature and gamma value to adjust the display transfer function and color balance. If the display is being set up to display sRGB-encoded images, then the target values are according to the sRGB specification [18]. The device may be a colorimeter or a spectrophotometer and measures values from displayed patches with known colorimetry on the screen, either in close contact with or some distance from the screen surface. The device software then creates a profile allowing transformation between the PCS and the device values, which, when applied in the device settings, will be used to adjust values on the video card.

The display viewing conditions have a significant impact upon the color appearance on the screen; hence viewing images on a display in a room illuminated by natural daylight or under different viewing conditions to those used during calibration and profile is unlikely to produce consistent results. As a general rule, the ambient lighting should be at a relatively low level, unchanging, and should not have a color cast. In sRGB the viewing conditions are specified and need to be set up prior to calibration and profiling.

9.8.2 Printer Calibration and Characterization

As described earlier, part of the calibration of a printer is the selection of a paper and ink or dye set, and the process must be performed for each new type of paper and colorant. If a printer is to print on different types of paper, with different white points or surface qualities, a profile will need to be created for each paper type. Because CMYK color spaces are not perceptually linear, a CIELAB linearization stage may also be included as part of the calibration, which involves printing a pre-profiling linearization target which has linear CMYK scales. Once printed, it is measured using a colorimeter or a reflection spectrophotometer. The profiling software then reallocates the CMYK output values to linear CIELAB values. This means that the CMYK values will no longer be linearly spaced but will appear visually equally spaced.

Next, the profiling target should be printed; this tends to have a far larger number of test values than for display profiling, and these are randomized. The measured values are compared to the reference file for the test target and a profile created based on a lookup table (LUT). The aim is for the target to be printed without color correction to test the default uncorrected behavior of the printer. The resulting profile should ideally be selected as the destination profile at the point of printing an image.

9.9 Color Differences, Perceptibility, and Acceptability Thresholds

Perceptually uniform color spaces allow the meaningful calculation of color differences. The $\Delta E^*_{a,b}$ metric is one of the most widely used color difference measures and may be calculated directly either from the differences between the CIELAB values or from the luminance, chroma, and hue difference values [17]:

$$\Delta E^*_{a,b} = \left[\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2\right]^{1/2} = \left[\left(\Delta L^*\right)^2 + \left(\Delta C^*_{a,b}\right)^2 + \left(\Delta H^*_{a,b}\right)^2\right]^{1/2.}$$

Color differences can be used to benchmark thresholds of perceptibility of various imaging attributes such as color under specific conditions, to identify tolerances in terms of color reproduction for an imaging device, or to explore the effects of changing settings or viewing conditions within an imaging system, thus helping to establish standards appropriate to imaging requirements.

The CIEDE2000 formula [22] is a more recent and complex color difference metric recommended by the CIE, developed to compensate for some non-uniformities in the CIELAB color difference metric. ΔE_{00} is derived from CIELAB values, adjusting the relative weightings of lightness, chroma, and hue components for various illumination conditions. The implementation is rather complex; a step-by-step explanation can be found in [23] and supplementary notes in [24].

Metrics such as $\Delta E^*_{a,b}$ and ΔE_{00} are useful in identifying how much a color has shifted as it moves through an imaging chain. However, to be meaningful, they must be tested and benchmarked using psychophysical experiments with human observers. This process allows values calculated from the metrics to be used to predict the perceptual significance of the differences.

In a typical psychophysical threshold experiment, observers evaluate pairs or triplets of colors to identify the level at which differences between them become perceptible. When a given proportion of observers can notice a difference (commonly either 50% or 75%), the point at which this occurs is known as the just-noticeable difference of perceptibility or JND. For an in-depth explanation of psychophysical experimental methods, refer to Engeldrum [25]. JNDs in this case are a measure of *color fidelity*. When the difference between the two colors is also evaluated with a color difference metric, it is possible to calculate the amount of color difference in $\Delta E^*_{a,b}$ that will produce a just perceptible difference. This allows a prediction of the threshold of color differences that may be tolerated within a given situation, providing a useful benchmark to which devices and systems may be designed and calibrated. The perceptibility of differences, or JNDs, in uniform color patches may be as low as 1.0 $\Delta E^*_{a,b}$ but is generally higher when colors are part of complex scenes.

JNDs of *acceptability* or acceptability thresholds may also be established through psychophysical experiments [26]; in this case they quantify the level at which perceptible differences become unacceptable in a particular imaging application. Such measures are useful in applications where color matching is important, such as prosthetic dentistry [27], where the JND of perceptibility has been found to be approximately 1.0 $\Delta E^*_{a,b}$, similar to that found for uniform color patches, while the JND of acceptability is at around 3.7 $\Delta E^*_{a,b}$. JNDs of perceptibility and acceptability are highly context dependent.

Tolerances for perceptibility and acceptability vary depending upon the requirements of the imaging application, viewing conditions, the subject and image properties, and the experience and expertise of those viewing the images. The thresholds for skin tones in various specialisms are a case in point. As described previously, the HVS is influenced by the memory color effect, which is formed by an observer from familiar objects, provided that they are strongly associated with a typical color [28]. Skin tones can produce significant errors when captured on digital cameras [11] and are also strongly associated with memory colors [29]. Research into color difference perceptibility and acceptability thresholds using artificial skin samples used for maxillofacial prosthetics found that the perceptibility threshold for light skin tones is 1.1 $\Delta E^*_{a,b}$ and the acceptability threshold 3.0 $\Delta E^*_{a,b}$. For darker skin tones the thresholds are 1.6 $\Delta E^*_{a,b}$ for perceptibility and 4.4 $\Delta E^*_{a,b}$ for acceptability.

Psychophysical experiments are a widely accepted approach to test and measure various aspects of the quality of imaging systems, to establish benchmark requirements for imaging standards and to compare the performance of different devices. However, they are intensive and time-consuming and thus often impractical in real imaging scenarios; therefore, having an objective metric such as ΔE, which correlates with human perception and can be derived from colorimetric measurements within an image, is extremely useful.

9.10 Summary

There is little doubt that color accuracy, consistency, and standardization are of key importance in medical photography, to monitor disease and assist diagnosis, and in areas where color matching is important. The increased use of mobile devices and true color images makes it imperative that some of the challenges are met in managing color in medical photography, especially in areas such as telemedicine where images may be transmitted and viewed across different systems and in different geographic locations. Various specialisms have developed individual approaches, but there is currently no common framework. The ICC MIWG has identified a number of key areas of work with the aim of providing a consistent approach and framework for the standardization of color. The reproduction objectives differ across clinical areas, with some necessitating a tailored approach, for example, the development of a color extension to the DICOM grayscale standard display function [30], which is useful for grayscale images with pseudo color overlays, for color visualization of quantitative information. In more general medical imaging, the requirement is for colors in images to be as visually consistent as possible with the original and for this color to be reproduced accurately across different sorts of devices, devices in different locations and in images taken at different times. The ICC color management architecture has the potential to provide a framework in which accurate color reproduction may be implemented. Current work by the ICC MIWG addresses some of the very specific solutions required for best practice guidelines in medical photography.

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Part IV

Basic Concepts and Equipment

Basic Photographic Concepts

10

Ali Johnston, Paola Pasquali, and Julio Estrada

Contents

10.1 Introduction

According to Merriam-Webster dictionary [1], photography is the art or process of producing images by the action of radiant energy and especially light on a sensitive surface (such as film or an optical sensor). While art has to do with a human intervention (one of Merriam-Webster's definitions for art is the conscious use of skill and

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creative imagination especially in the production of aesthetic objects), the process of producing photographic images depends heavily on the pieces of equipment used by the photographer. In this chapter we will focus on the basic photographic concepts related to the principal piece of equipment: the camera. Other accessories such as lighting equipment, camera supports, and filters are treated in other chapters. It probably sounds better this way: This is an introduction to the main concepts of digital photography that a seasoned photographer might find simplistic. Our task here has been to organize information already available in many places (books, webpages, and other sources) in a logical way to make life easier for the beginner in medical photography. Technical information is included when relevant to the subject.

Medical photography needs to be quality photography. Only with good-quality images the physician or other health professionals will be capable of making correct diagnoses, record the patient's condition, monitor illness evolution, and teach others. Even those that are not professional photographers but use medical photography as part of their practice will need to know and understand the basic concepts of photography even when using smartphones or tablets. We hope the reader will find all the needed information to set the camera for good-quality clinical pictures.

10.2 The Digital Photographic Process

Starting with the first 1839s daguerreotypes, the history of photography has transited through many different photographic processes before the arrival of the digital process we use today. In this chapter we only deal with digital photography.

In the digital photographic process, light reflected by the subject passes the camera lens that focuses the image on an electronic sensor device (either CCD or CMOS/APS technology). Inside the camera the sensor image is processed with the help of a digital signal processor (DSP) chip and then stored in the form of a RAW or JPEG file. A RAW file is the equivalent to a film negative. With the help of photo-editing software, the image can be adjusted to fit the needs of the photographer and visualized in a digital display; this process is comparable to the old developing film photos. Finally, the image can be printed on paper (Fig. 10.1).

10.3 Digital Cameras

Technically, photography has to do with the creation of durable images from light or electromagnetic radiation (such as x-rays) as reflected and then directed from a subject into a camera device. For good quality pictures, such as those required

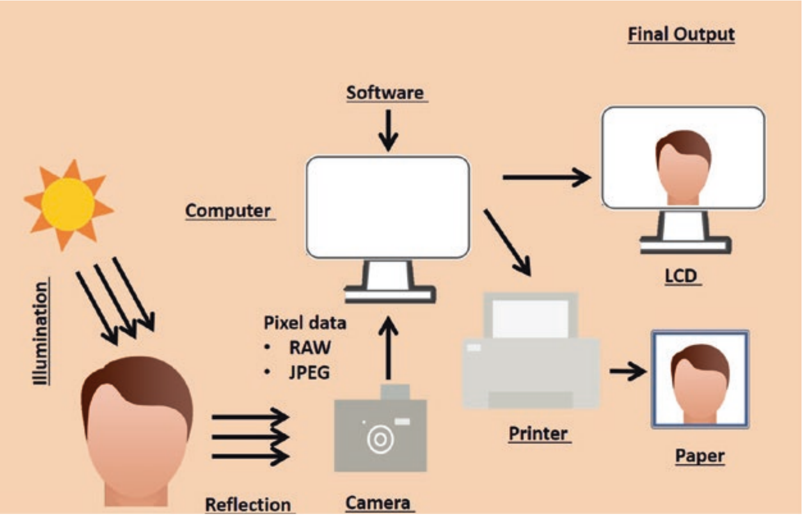


Fig. 10.1 Graphic representations of the digital photography process. (Redrawn from Linkwitz Lab© 1999–2019 LINKWITZ LAB, All Rights Reserved) [2]

for medical applications, the photographer must use the proper lens in order to adjust to varying object conditions, given that a single lens cannot well satisfy the needs of different photographic tasks. Interchangeable lens cameras are thus a necessary tool for quality pictures. The previous chapter on equipment (Chap. 11) has dealt with cameras. The two types more relevant to the scope of this chapter are those with interchangeable lenses: DSLR and mirrorless cameras, although smartphones are particularly useful for some medical applications.

Digital cameras can be classified into different types: digital single-lens reflex (DSLR or dSLR), mirrorless (or CSC), bridge (also called superzoom), advanced-compact (also called zoom-compact), adventure cameras, and smartphones. The two types more relevant to the scope of this chapter are those with interchangeable lenses: DSLR and mirrorless cameras, although smartphones are particularly useful for some medical applications.

Compact digital cameras, also known as point-and-shoot cameras, are very simple to use but not well suited for medical photography. Given that the individual components of the camera are of a lesser quality and that lens and some photo parameters cannot be changed to better adjust for subject condition, the quality of the image is poor. Point-and-shoot cameras are affordable, light, and easy to use, but they do not render the quality required for good medical photography.

Advanced-compact cameras, although still far away from CSC/DSLRs, are a step forward in the direction of better-quality images given that they provide for manual control, RAW files, and an attached focal-length adjustable telephoto lens.

Bridge cameras are in between advanced-compact and CSC/DSLRs. They feature a non-interchangeable zoom lens covering wide to telephoto focal lengths. With a DSLR-style handling, they feature automatic and manual shooting modes and a full range of creative controls. Bridge cameras are smaller, lighter, and less expensive than interchangeable-lens cameras, but their image quality is sub-optimal.

DSLRs and CSCs are delicate pieces of equipment that are not meant for use under rugged conditions. Adventure cameras, designed for adventure sports (extreme sports or action sports) involving a high degree of risk, are small, lightweight, waterproof, mud (anyone said blood or human fluids?) resistant, wearable, and shockproof and come with ample mountability options. Although ideal for video, their average resolution of 12 MP (best adventure cameras are in the range 8–16 MP) and hands-free operation make them a good compromise solution for taking acceptable quality images (or videos) under very adverse conditions. For field hospital situations, for forensic medicine, and even for recording surgical procedures in operating theaters (ORs), adventure cameras can be a practical solution for capturing medical images that could not be done using DSLR cameras/CSC.

For certain medical uses, smartphone's cameras have become the best alternative because of their availability (you always carry it in your pocket), lightness, easiness to use, and affordability. They are the subject of another chapter in this book (Chap. 13).

Today, most of the professional interchangeable-lens digital cameras are DSLR that have a vision system that allows the photographer to see in the viewfinder exactly what will be recorded by the sensor. DSLR cameras use basically the same optic design as the 35 mm film cameras of days gone by, but an electronic sensor substitutes the photographic film for capturing the image. The fundamental mechanism of a DSLR camera is a moving mirror that with the help of a pentaprism (or penta-mirror) re-directs the focused image towards the viewfinder when focusing or towards the camera sensor during exposure. By doing so, it is placed in such a way that the left, right, top and bottom of the image mimic the subject as seen through the eyepiece. When the shutter mechanism is activated, synchronically the mirror rises and the shutter opens so that the chosen light reaches the sensor, exposing it to incoming light. To finish the cycle, after the time adjustment has elapsed the mirror returns to its place and the shutter closes back (Fig. 10.2).

It's complicated and expensive to build DSLR cameras with the mirror-viewfinder mechanism. As opposed to DSLRs, mirrorless cameras also known as mirrorless interchangeable-lens cam-

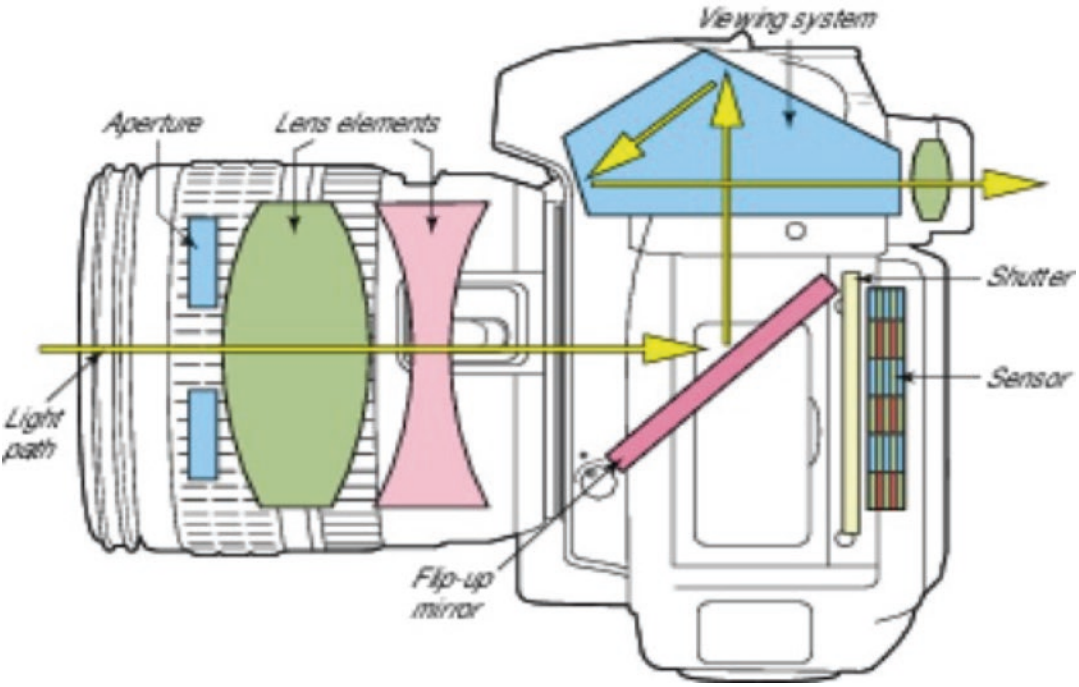


Fig. 10.2 Viewer light path in a digital single-lens reflex (DSLR) camera. (Courtesy of © 2020 Stack Exchange Inc.; user contributions licensed under cc by-sa 4.0 with attribution required. rev 2020.3.31.36413, All rights reserved) [3]

eras (MILC), compact system cameras (CSC) or hybrid cameras have neither a complex mirror system nor a viewfinder (Fig. 10.3). Just as with DSLR cameras, mirrorless cameras feature the interchangeability of lenses. Although SLR cameras have been the cameras of choice for professionals for many decades, even before the digital versions were born, mirrorless cameras seem to be the wave of the future. Having most of the features of DSLR cameras, mirrorless cameras are smaller, lighter, and less expensive than DSLR cameras. Many CSCs even have Wi-Fi capability allowing to remotely control the camera and sending of images.

Nowadays, a good-quality picture can be achieved either by using high-level DSLRs or CSCs with the right sensor quality.

10.3.1 Sensor Size and Crop Factor

A sensor is that key part of the camera (Fig. 10.2) that captures an optical image and turns it into a digital one. It does so by converting incoming light into electronic signals. A sensor digitalizes optical images. Physically, a sensor is a matrix of small pixels (*pic*ture *el*ements). Pixels, the tiny components of a sensor, are the units that capture light and turn it into data. Both sensor size and pixel count are important for good-quality photography.

Sensors are manufactured using two alternative manufacturing technologies: charge-coupled device (CCD) or complementary metal-oxide semiconductor (CMOS). CCD was the first sensor technology, developed by Kodak in 1986. The “traditional” CCD sensors are being taken over by CMOS. The advantage of the semiconductor technology is that it is more affortable and its quality has achieved levels comparable to or even better than CCD. The future seems bright for CMOS: it is becoming the new “standard”; CCD might remain valid for some special applications such as very fast photography where CMOS tend to produce an undesirable “jello” effect [5].

Other things being equal, the bigger the sensor, the better the quality of the picture given that

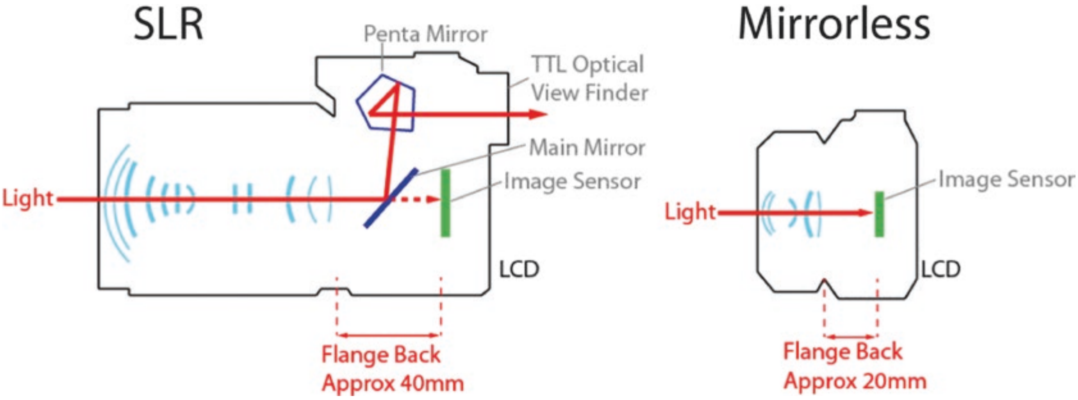


Fig. 10.3 Illustration showing the light path in DSLR and mirrorless cameras. (Courtesy of © 2011–2017 VnReview, All rights reserved) [4]

a bigger sensor allows for larger pixels that can individually capture more light and in turn render a better picture. In the vast majority of either DSLR or mirrorless cameras, the biggest sensor size is 34 × 24 mm, the same size of a “full-frame” 35 mm film negative with an aspect ratio of 3:2. The sensor is expensive to build, so more affordable cameras use smaller sensors. When full-frame sensors were first introduced, production costs could exceed 20 times the cost of a smaller size APS-C sensor [6]. Also, a smaller sensor allows for smaller, lighter, and more affordable camera bodies and lenses. More compact cameras do have smaller sensors. Different camera manufacturers adopt different sensor size but in general keeping the traditional 3:2 aspect ratio inherited from the old 35 mm film. Advanced Photo System (APS) is an old movie and TV standard for sizing film negatives that in a similar way as the 35 mm film standard is used today in digital photography (the outer diameter of the vacuum tube needed to produce a usable image of up to two thirds of the circular image obtained serves as the reference for tube size). In both its C and H versions, the APS format holds on to the 3:2 ratio (Fig. 10.4). But not all sensors hold to the 3:2 standard. The “Four Thirds” sensor created with the participation of Eastman Kodak and used by Olympus and Panasonic as part of the Four Thirds System have a less “panoramic” format, close but not equal to 4:3, although the system can crop images to the 3:2 ratio [8].

Crop factor is the ratio of the diagonal of a given sensor to the diagonal of the full-frame sensor. It is a measure of sensor size relative to full-frame. By definition, a full-frame sensor has a crop factor of 1.0. A sensor smaller than full-frame has a crop factor greater than one: it “crops” the image to a fraction of full-frame. Relative sensor sizes for different crop factors are shown in Fig. 10.5, although the “cropped” image corresponds more to the center of the full-frame’s area, as shown in Fig. 10.8.

The APS-C format (23.6 × 15.6 mm) has a crop factor of 1.53 (see calculation in Table 10.1)

Different camera manufacturers chose to use particular sensor sizes to adapt them to a full family of bodies, lenses, and other accessories. This is to say that a particular manufacturer does not produce all sensor formats, but a limited number of them. It can be confusing because even the APS-C format corresponds to different sensor sizes depending if it is in a Nikon or in a Canon camera. As full-frame is always 36 × 24 mm, and to calculate the crop factor of a particular camera, it is best to use the actual sensor size in millimeters given by the manufacturer. Table 10.2 and Fig. 10.6 show sensor sizes and crop factors for common digital cameras.

For special applications, camera manufacturers have developed some sensors larger than full-frame. The “medium-format” sensor is 48 × 36 mm (crop factor 0.72) for most manufacturers or even larger for others. Medium-format is mostly associated with film photography, but a

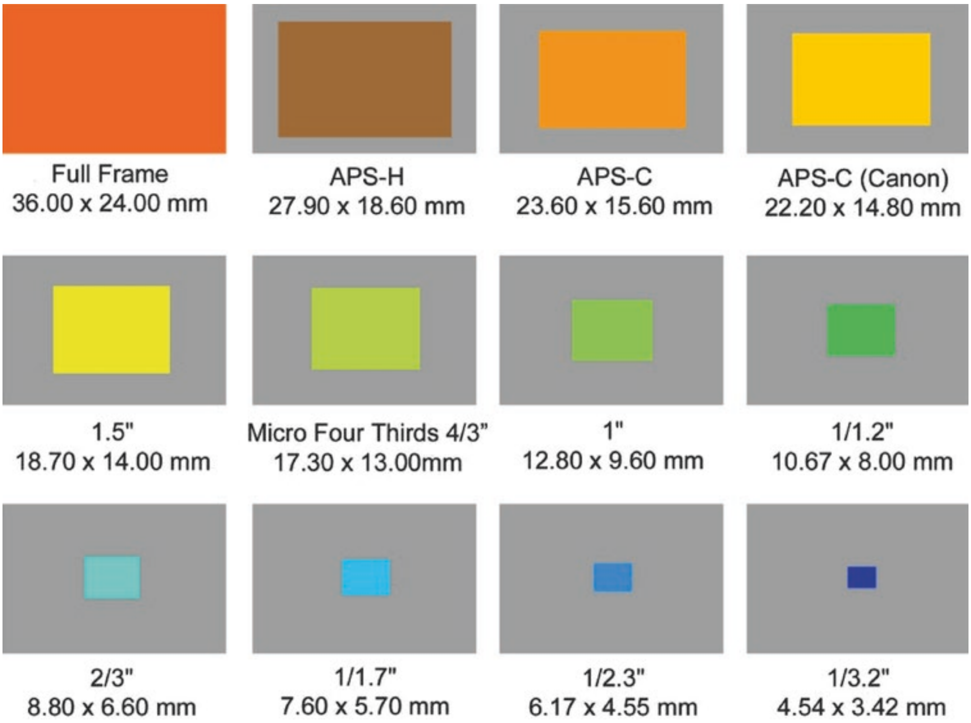


Fig. 10.4 Sensor size relative to full-frame. (Courtesy of Simon Crisp © 2020 New Atlas, All rights reserved) [7]

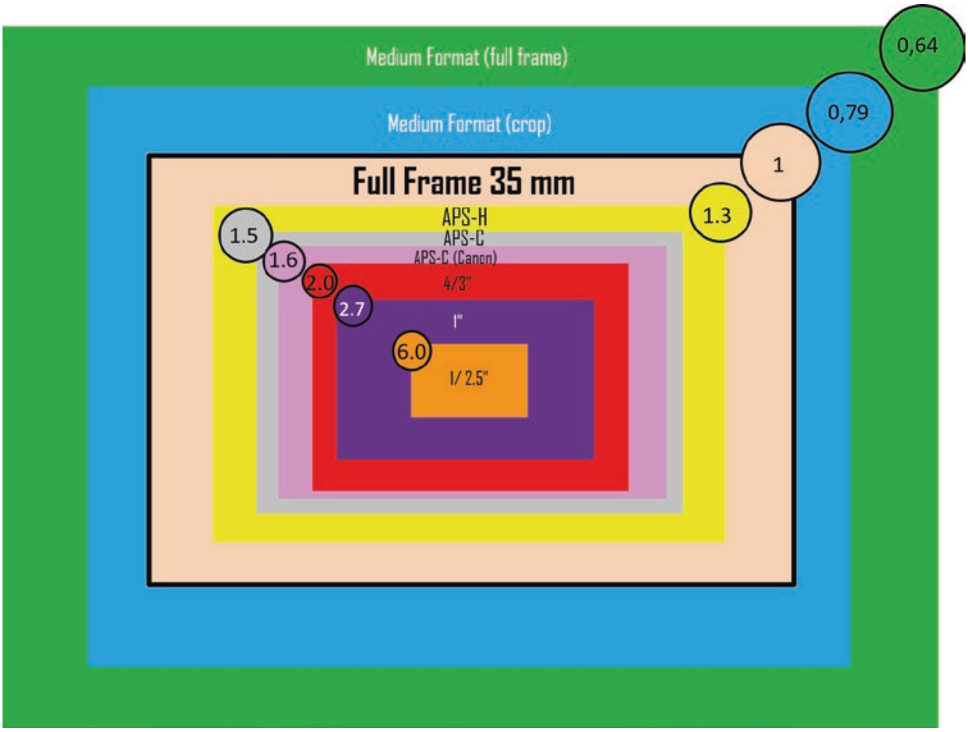


Fig. 10.5 Digital sensor relative size and corresponding crop factor

Table 10.1 Calculation of crop factor for APS-C sensor

Full-frame size: 36 × 24 mm Full-frame diagonal: 60 mm
APS-C size: 23.6 × 15.6 mm APS-C diagonal: 28.3 mm
APS-C crop factor = APS-C diagonal/full-frame diagonal = 1.53

Table 10.2 Common sensor sizes used on DSLR camera/CSC[a]

Format	Dimensions, mm	Area, mm^2	Crop factor	Aspect ratio	Brands
Full-frame	36 × 24	864	1.00	3:2	Pentax, Panasonic, Leica, Nikon, Canon, Sony, Sigma
APS-H	28.7 × 19[b]	545	1.35	3:2	Sigma
APS-C	23.6 × 15.6[b]	368	1.52	3:2	Nikon, Pentax, Sony, Fujifilm, Sigma
APS-C Canon	22.3 × 14.9	332	1.61	3:2	Canon
Four-thirds	17.3 × 13	225	2.00	4:3	Olympus, Panasonic, Black Magic, Polaroid

[a] Less priced mirrorless cameras may use smaller sensors sized 1″ or 1/2.3

[b] Real sensor dimensions can vary from model to model

handful of manufacturers make digital medium-format photo cameras (Pentax, Hasselblad, Leica, Mamiya, and most recently Fujifilm). Medium-format cameras are much more expensive than full-frames, ranging from US$ 5000–30,000 for the body alone. A bigger sensor area requires larger diameter lenses. Lenses for medium-format cameras are also more expensive and bulkier than full-frame's.

For academic astrophotography Canon developed a sensor 200 mm (7.8 in.) on each side. The sensor was used at the Kiso Observatory of the University of Tokyo to discover new meteors [10]. The Japanese researchers could capture information impossible to spot using previous imaging equipment.

Cameras with sensors smaller than full-frame crop the image to a fraction of what the image could have been at full-frame (considered the standard). If using the same lenses, reducing sensor size reduces the angle of view (the image "viewed" by the sensor is only a portion of the image captured by the lens) (Fig. 10.7).

A DSLR camera with an APS-C size sensor (crop factor 1.5) would crop into the full-frame image. The image will be cropped 1/3 (the inverse of 1.5) as compared to full-frame. It is common practice to express focal lengths of lenses for non-full-frame cameras in equivalents of full-frame's focal lengths, based on angle of view similarity. For example, the angle of view with a 45 mm lens on full-frame will be equivalent to the one for a 28 mm lens on an APS-C size sensor (the 28 mm APS-C's lens would be referred as a 45 mm full-frame focal length equivalent). The longer focal length on a full-frame camera narrows the field of view (telephoto effect) in a similar way a shorter lens (wider view angle) on a smaller sensor camera would do. Fractional (sub-full-frame) sensors (like the ones in smartphones and other devices with very small sensor sizes) will need to use wider angle lenses (much lower focal lengths) to maintain the same angle of view. The smaller the sensor size, the wider the lens required for the same view angle. A cell phone with a 28 mm full-frame-equivalent focal length will have a real focal length in the range of 3 mm (depending on the size of the sensor). In Fig. 10.8 the crop effect is shown for different common sensor sizes.

Fractional sensors of sizes equal or smaller than nominal 1 in. are commonly used in mirrorless, point-and-shoot, and smartphone cameras. Physical dimensions for common fractional sensors up to nominal 1 in. can be seen in Table 10.3 and Figs. 10.5 and 10.6.

10.3.2 Pixels and Resolution

A pixel is the smallest addressable unit of a digital image and the smallest physical element of a digital display device that the eye can discern [12]. In a sensor, a pixel is a photosite, the smallest indepen-

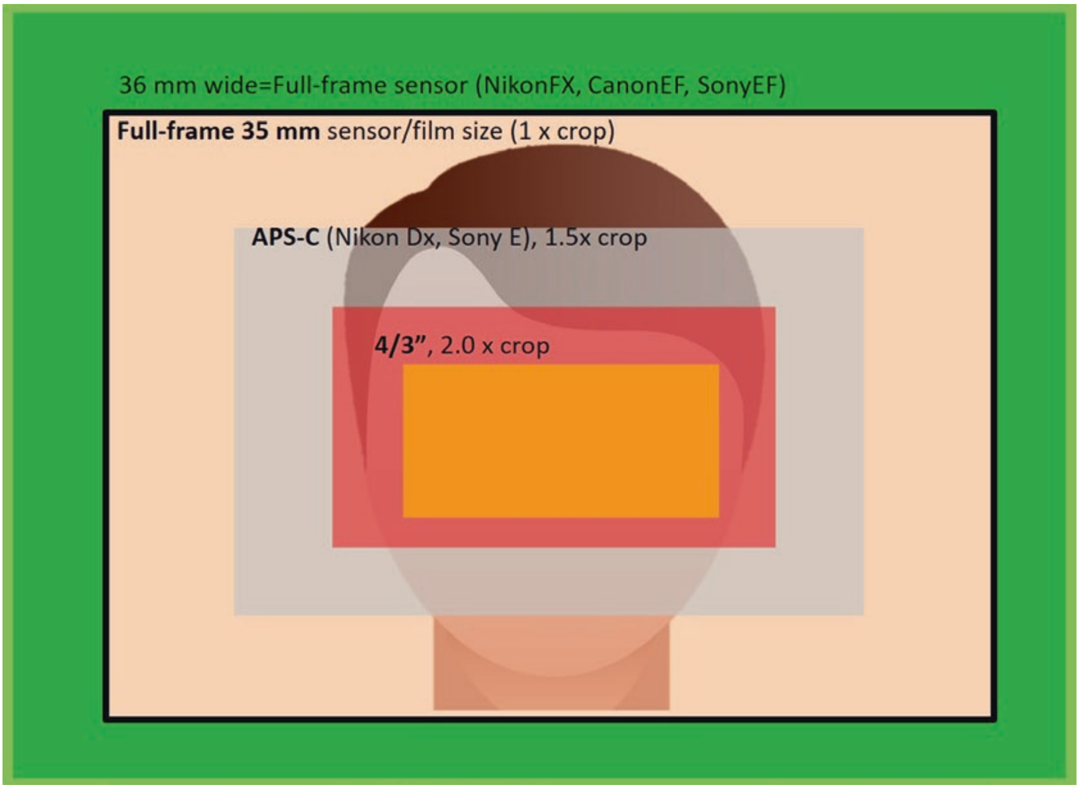


Fig. 10.6 Sensor size comparison for digital cameras. A full-frame sensor (36 × 24 mm) is a standard for comparison, with a diagonal field-of-view crop factor = 1.0 (black box). Bigger sensor area (green box) captures better quality but requires larger-diameter lenses (smartphones compensate for tiny sensors via computational power). APS-C (gray box); Aps-C Canon (violet box). For example: an APS-C (gray) sensor gathers 2.3 times less light (area) than a full-frame (1× crop) and 1.6 times more than a 4/3″ sensor (2.0× crop, red box) [9]

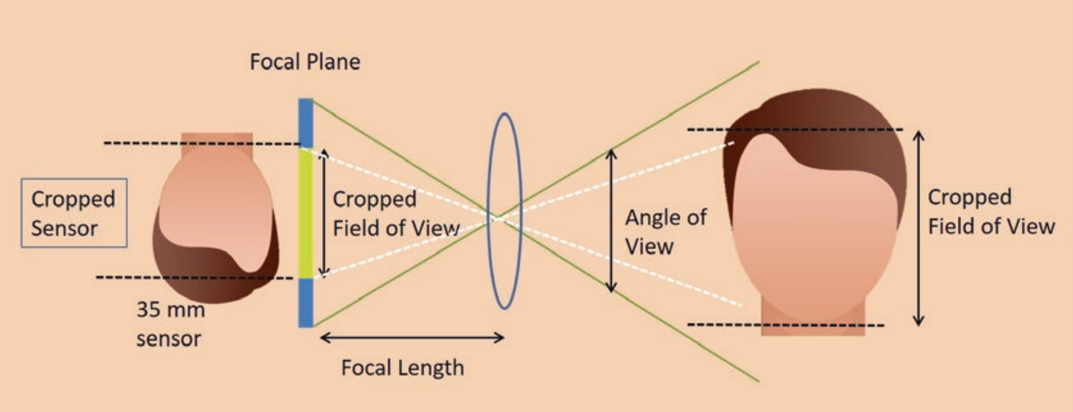


Fig. 10.7 The cropped sensor "sees" a narrower angle of view [11]

dent semiconductor element that can absorb photons and liberate electrons; in a digital display, a screen pixel is the smallest unit that can show a uniform color. Resolution for both image files (in formats such as TIF, JPEG/JPG, GIF, PNG, or RAW) and digital displays is measured in pixel dimensions (such as 2048 × 1536 pixels or 3.1 MP) or as a density in pixels per inch (PPI) on each axis.

Printed images are created using dots of ink. Printer resolution is the density of physical ink

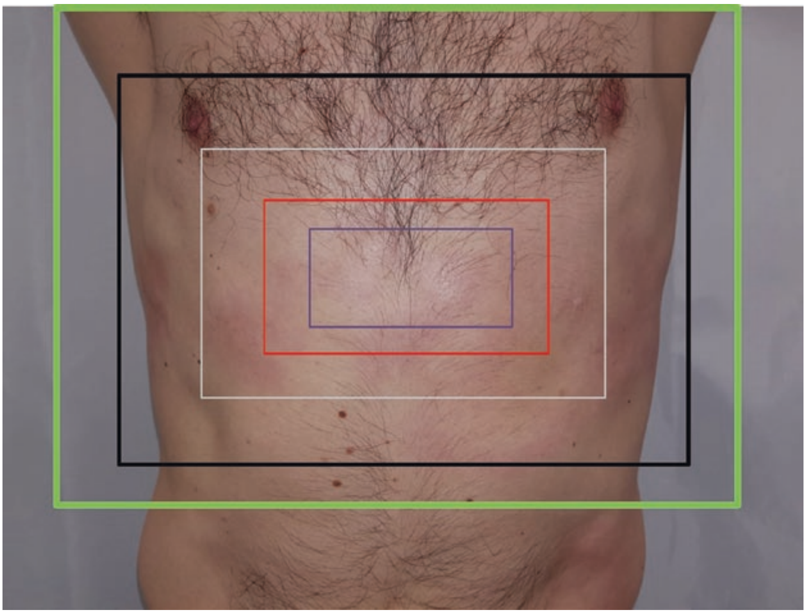


Fig. 10.8 Image crop and sensor size. *Green line*, 36 mm wide (full-frame sensor); *black line*, full-frame 35 mm sensor; *gray line*, APS-C; *red line*, 1″ sensor; *purple line*, 2/3″ sensor [7]

Table 10.3 Common sensor sizes 1 in. and smaller[a]

Format	Dimensions, mm	Area, mm^2	Crop factor	Aspect ratio	Brands
1″ (1 in.)	13.2 × 8.8	116	2.7	3:2	Nikon CX, Samsung NX, Sony RX
1/1.7	7.6 × 5.7	43.3	4.55	4:3	Pentax Q7, Canon G10, Huawei P20Pro, P30Pro
1/2.3	6.16 × 4.62	28.5	5.64	4:3	Nokia Lumia, Pentax Q, Sony, GoPro, Panasonic, Google Pixel
1/2.5	5.76 × 4.29	24.7	6.15	Approx. 4:3	Nokia, Sony, iPhone
1/2.6	5.5 × 4.1	22.6	6.30	Approx. 4:3	Samsung Galaxy S6, S7, S8, S9, S10, Note 5, Note 9
1/3	4.8 × 3.6	17.3	7.21	4:3	LG, iPhone 8, 7, 5S

[a] Common on mirrorless, point-and-shoot, or smartphone cameras

dots per inch (DPI) of paper, although the pixel/dot conversion rate when printing digital images can change from one printer manufacturer to another (the number of image pixels combined to make one dot can be different) making it more complicated to correlate DPIs from one printing equipment to another. There is a lot of confusion in the market about PPIs and DPIs. They are not the same. A camera sensor is a matrix array of individual physical cells (sensor pixels); a digital image file is formed by a matrix array of small bits of information (image pixels). Video monitors have a fixed amount of lines that in turn have a fixed amount of displaying points (screen pixels), and printers produce ink dots (although some people wrongly talk about pixels when referring to print density). A printed photo is an array of ink dots, never pixels (Fig. 10.9).

Printed images should have at least 300 DPI on its less dense side to show a good-quality image to the eye. Although 300 DPI is considered a standard for good-quality printed images, although 200 DPI could be acceptable; most medical journals/editorials require 300 DPI. At 150 DPI, printed images will have visible pixels and details will look “fuzzy.” Today’s laser printer’s standard resolution is 600 × 600 DPI or 1200 × 1200 DPI (a printer needs at least 4 ink dots to reproduce one colored image pixel). For top quality printing, a 400 DPI image is recommended. So, 200 DPI can be acceptable, 300 DPI is required for good quality, and 400 DPI is advisable for top quality printing.

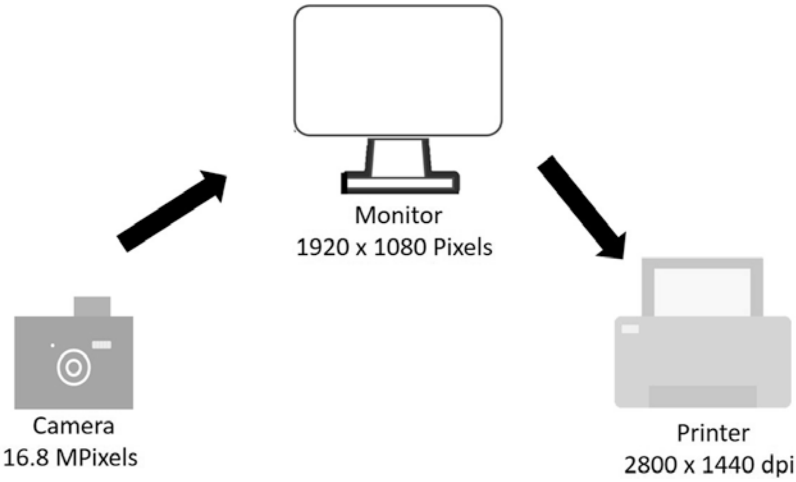


Fig. 10.9 Image resolution is expressed differently on each media

Table 10.4 Minimum image resolution required for good-quality printing (300 DPI)

Photo size, in.	Minimum MP
4 × 6	2.2
6 × 8	4.3
8 × 10	7.2
8 × 12	8.6
10 × 12	10.8
10 × 15	13.5
11 × 14	13.9
12 × 16	17.3
12 × 18	19.4
16 × 20	28.8
20 × 24	43.2
24 × 30	64.8
24 × 36	77.8
30 × 45	121.5

The selection of the camera resolution will be determined by the biggest photo that would need to be printed at top quality. At 300 DPI, a 10 MP camera can be the right choice for an 8 × 12 in photo but not for an 11 × 14 in print (Table 10.4).

When it is time to transfer the digital image to a screen or to paper, one can match each image pixel to a screen pixel or to a printable color dot at a ratio of 1:1 to calculate the maximum render size of the photograph (or the minimum size of the camera sensor needed).

Referring to a minimum MP value suggests that it is better to start with the highest resolution and image dimensions you can afford because images can always be downsized without losing quality; the opposite is not possible.

10.3.3 Adjusting Image Size Setting in Your Camera

Your camera will allow you to manually adjust image size (e.g., within Shooting Menu in Nikon), thus reducing the number of pixels used to build the image to a fraction of the total sensor resolution (only a section of the sensor is used to capture the image). Unless you find a good reason for doing so, it is always a better option to go for the full sensor resolution size your camera allows.

10.3.4 Sensor Pixels and Bucket Analogy

Light can be represented by small particles called photons. A photon, an elementary particle, has no rest mass and in a vacuum always moves at the speed of light. A sensor is an array of pixels. Each pixel (a photosite) is made from a semiconductor material that absorbs photons and liberates electrons into an electrical circuit.

The electrons are gathered by the sensor cells and held in voltage wells that prevent electrons from drifting away. The bucket analogy is commonly used to explain pixels (let’s call it pixel-bucket analogy). The bucket (the pixel) is under the rain (photons) holding rain drops. The bigger the bucket (pixel), the more rain drops (photons) get captured (Fig. 10.10). There is another bucket analogy (let’s call it exposure-bucket analogy)

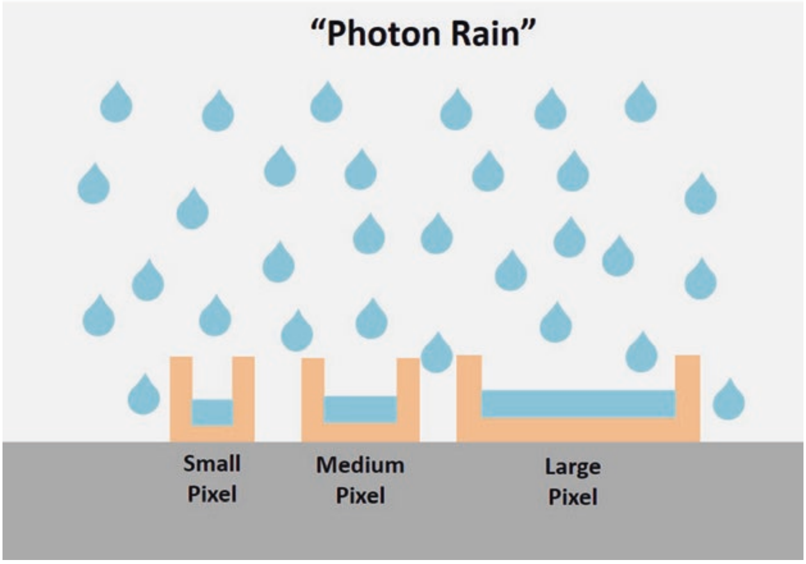


Fig. 10.10 Schematic illustration of the bucket-pixel analogy 1 [13]

successfully used in photography to explain the exposure triangle; you can check it online in Photography Life [14].

Continuing with the bucket-pixel analogy, let us now introduce funnels to collect rain drops into the buckets. A focusing lens delivering photons to a pixel is analog to a funnel that concentrates rain drops into a bucket. In Fig. 10.11 two different cameras are represented, one with a pixel size that doubles the other. If pixels don't overflow and lens apertures are the same, both pixels collect the same light (if funnel aperture is the same, rain drops gathered by the two buckets are equal). But when the smaller sensor saturates and starts overflowing, the bigger sensor still has additional capacity to continue receiving light (information) without overflowing (saturation). Pixel saturation occurs when the incident light at a pixel causes one of the color channels of the camera sensor to respond at its maximum value. Pixel saturation causes undesirable artifacts (e.g., loss of detail due to higher noise) in digital color images [15].

10.3.5 Noise

The light that leaves the subject carries the information to form an accurate image of it, be it in our eyes or in a digital image. From the time light leaves the object until the time an electronic image is stored in the camera, "noise" (unwanted information) is added up in every step. Pixels capture light and turn it into data. That data is made up of both good and bad information. The bad information is called "noise." The image information is the clean original information emitted by the subject; noise is any other "signal" that is added in the photographic process. What a good-quality camera does is to reduce noise at every level.

Let us imagine that during the exposure time we can avoid any movement of the subject or the camera; we might have eliminated blur but still we could be getting a grainy image. *Shot noise* is that part of noise caused by tiny variations in the light reflected from the subject during exposure time, due to the random behavior of photons (light can be considered as a stream of photons traveling as infinitesimally small discrete (quantized) packets with a random probability distribution; their random variations are shot noise) [16].

The other component of noise, particular to each camera, is *digital noise*; it is generated by the sensor and other camera electronics and can be made evident by a lens cap photo (when taking a long time exposure photo with the lens cap on, the resulting photo is not completely black).

Noise results in lower color saturation and a grainy or textured look to the image. Pixel satura-

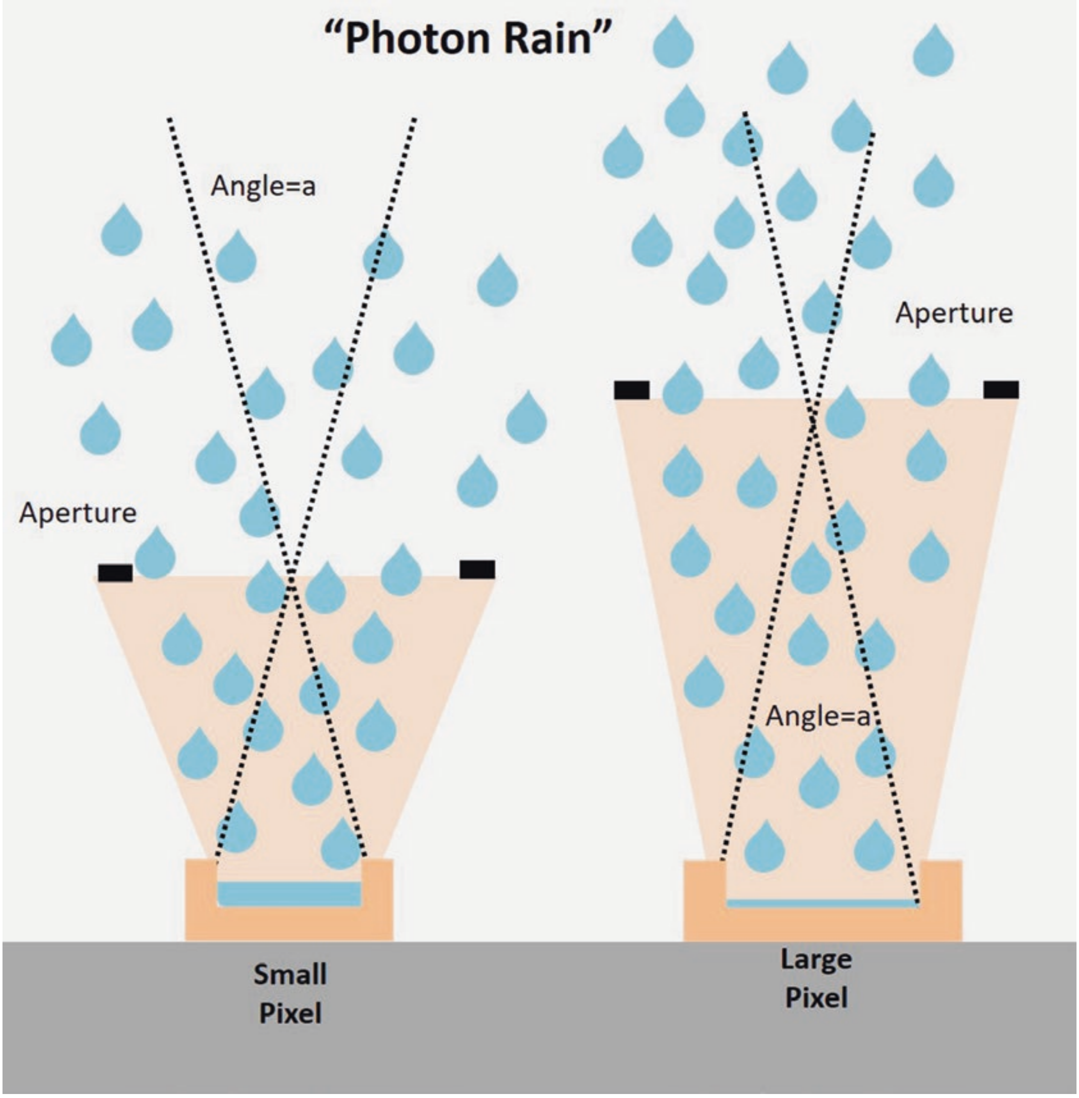


Fig. 10.11 Schematic illustration of the bucket-pixel analogy 2 [15]

tion occurs when the incident light at a pixel causes one of the color channels of the camera sensor to respond at its maximum value [16]. Pixel saturation can produce undesirable artifacts in digital color images. All pixels collect the same amount of noise, but larger pixels collect more of the "good" data than smaller pixels. All other things being equal, a larger pixel will result in a higher-quality image (less noise) than a smaller one. As we adjust upward the ISO (sensor sensitivity) of our cameras, noise rises too, making it more visible. That is why if you want to get the best quality out of any digital camera, you want to shoot at the lowest possible ISO. And if you must raise the ISO, then the larger the pixels, the better chance of still obtaining good-quality images. Despite what most people think, fewer pixels can sometimes mean better-quality pictures, as long as they are of a bigger size. As a general rule: the bigger the pixels, the lower the noise and the better the image. Many factors do affect the noise level of the final picture, including exposure (mainly the ISO setting), quality of the lens arrangement, software used to process

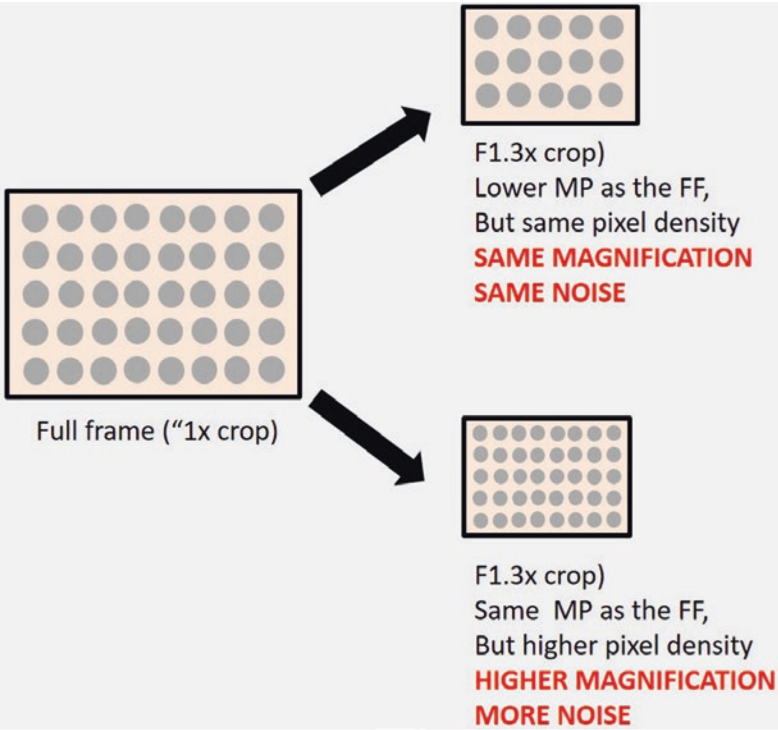


Fig. 10.12 Effect of sensor MPs on image noise

RAW formatted images, and sensor design. The best-quality picture happens when noise is minimized, being pixel size followed by sensor's pixel density—the most important noise-reducing factor.

Other things being equal, sensor's pixel density, not megapixels, defines the quality of the captured image. Pixel density relates to pixel size (how many pixels per area unit, e.g., Canon 5D Mark IV has a pixel density of 3.48 MP/cm^2). A fractional (smaller than full-frame) and a full-frame sensor with equal pixel density produce the same noise. The more relevant attribute for quality images is the pixel size, not the MP (Fig. 10.12).

10.3.6 Image Formats: JPEG vs. RAW

All DSLRs and CSCs offer the choice of two image quality formats: JPEG and RAW. Some high-end smartphones support RAW format as well. JPEG is a codification and compression standard for filing still images created by a group of experts called Joint Photographic Experts Group. The file extension JPEG is used in Mag image files, whereas in Windows the file image extension used is JPG. JPEG and JPG are exactly the same. When the camera stores JPEG images, all the camera settings made when shooting get embedded in the file (all camera settings become part of the stored image and you will not be able to undo them). All image adjustments should then be applied before JPEG file storage. Apart from photographic adjustments, images in JPEG format are also compressed to save memory space. Different degrees of JPEG compression can be set in your camera, ranging from Basic to Fine. Basic JPEG has the highest compression level and consequently reduces the most quality of the image (Basic JPEG setting is best avoided). Fine JPEG uses a minimum degree of compression, thus obtaining the highest image quality in a JPEG.

On the other hand, RAW (NEF in Nikon cameras) is a file format used to store unprocessed images (a RAW file is comparable to a film photo negative). A RAW image is the "untouched" file, with the largest amount of information. To further use it, RAW images will have to be digitally processed using image-editing software and then resaved. A RAW file can be edited for white balance, contrast, saturation, and even exposure. The changes made on the image become part of it when the RAW file is resaved (once resaved, the changes to the RAW file cannot be undone).

Most cameras give the option to save simultaneously two images of the same shot but with different formats: RAW and one of the JPEG options. Given the low cost of memory cards and relevance of detail for medical photography, our recommendation is to go for the combination RAW + JPEG file.

10.3.7 Lenses

Once the camera body is selected, the choice of lens is the most important decision with regard to photographic equipment. Lenses can be classified into different categories: super wide angle, wide angle, normal, telephoto, super telephoto, and variable focal length.

It is important to "read" all the information found on the lenses. An example is shown in Fig. 10.13. This lens has a variable focal length from 16 to 35 mm, with 2.8 maximum aperture and the threads are made for accessories 82 mm in diameter. USM stands for Ultra Sonic Motor (this lens has an autofocus faster than standard models); Canon uses a standard lens mount called EF (Electro-Focus) because it has a built-in motor in the lens for automatic focusing.

10.3.8 Focal Length

The focal length of a lens, expressed in millimeters, is the distance along the lens' optically central axis to the image plane (the digital sensor or film plate) when the lens is focused to infinity (Fig. 10.14).

The focal length is not an external measurement on the lens body. The focal length has to do with the optical behavior of the lens, with its point of convergence (inside the lens the light that enters converges in a point called point of convergence, before hitting the sensor). In Fig. 10.14, a focal length of 28 mm is the distance between the point of convergence of the light inside the lens and the plane of the digital sensor, where the image is captured.

Fig. 10.13 Description on outer ring for a Canon lens. (Courtesy of © Canon Inc., All rights reserved)

10.3.9 Distortion

Distortion occurs when parallel lines appear curved. It affects both the vertical and horizontal axes of the image and is more evident in images that involve real-life parallel lines (especially when those lines are closer to the image's borders). In photography, there might be two types of distortion: optical and perspective. Optical distortion (also named lens distortion) is caused by the optical design of the lens. Perspective distortion is caused by the position of the camera relative to the subject or by the position of the subject within the image frame.

Optical distortion is a consequence of lens construction. Wide angles do have more distortion then medium or telephoto lenses, although all lenses—even prime—can also have it. Optical distortion can be one of three types: barrel, pincushion, and mustache (Fig. 10.15). Barrel dis-

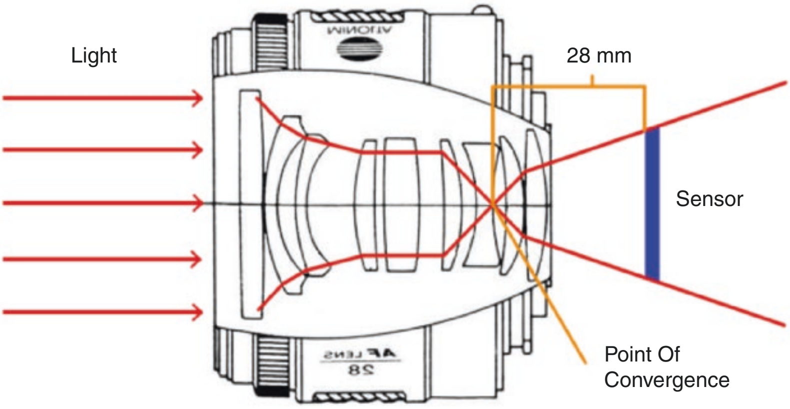


Fig. 10.14 Showing a 28 mm focal length lens. (With permission of Josh Dunlop. Expert Photography © 2011–2019. All Rights Reserved) [17]

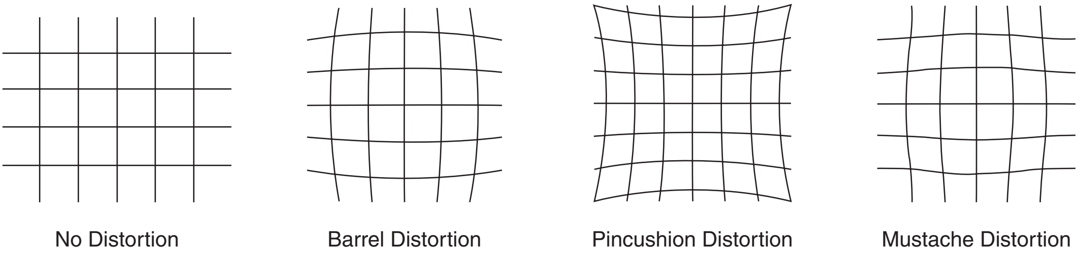


Fig. 10.15 Types of optical (lens) distortions

tortion is more common in wide-angles and pincushion distortion in long telephotos.

A distortion is called barrel when real-life straight lines are curved inward in the periphery of the image, resembling a wooden barrel such as those used to store wine. Barrel distortion increases with shorter distances to the subject or by using wide angles. Barrel distortion is more obvious with wide-angle lenses because the field of view of the lens is much wider than the size of the camera sensor and hence the image needs to be "squeezed" in to fit the smaller sensor size. Barrel distortion diminishes with focal length until it becomes pincushion distortion in long telephoto lenses.

Pincushion distortion is the opposite to barrel distortion. Here, the image becomes pinched in the center as in a pincushion when a pin is pushed in: under pin's pressure the fabric moves down. Pincushion distortion is more common with telephotos and particularly with zooms at the upper end of their focal-length's range, being the bigger distortion toward the border of the image, away from the lens axis. There is a much higher degree of barrel distortion with wide angles than pincushion distortion with long telephotos.

As a rule of thumb, to avoid distortion in portrait, use a lens with FL in the range 70–100 mm. FL less than 70 would make the barrel distortion evident: the face will look thinner and the nose would look enlarged (remember the enormous Pluto nose in that close-up photo?). With lenses above FL 100 mm, the face will look rounder; the pincushion effect in the periphery of the image will cause that effect. The barrel effect is much more detectable and annoying to the eye than the pincushion effect; the brain tolerates more pincushion distortion than barrel (Fig. 10.16). In medical portrait photography, where distortion has to be avoided, the selection of lens' FL becomes a priority.

As with the human eye, perspective distortion in photography is a consequence of placement of the camera in relation to the subject. Obviously, an object close to the camera will look bigger than when placed far away. In architectural pho-

Fig. 10.16 Distortion caused by focal length. (Reproduced with permission from Stephen Eastwood. All Rights Reserved) [18]

tography parallel lines appear to converge. In the case of portrait photography, such as those for recording clinical images of patients, a wide-angle lens close to the patient's face would distort the reality by stretching the nose and shrinking the ears, a situation to be avoided. Although some convergence defects such as converging parallels can be fixed by using editing software, it becomes a time-consuming chore and unnecessary if for a start the image was taken with a prime or telephoto lens at not too close to the subject.

Distortion is not to be avoided all the time. In art photography, distortion can be a very good resource for creative images.

10.3.10 Perspective

According to Cambridge Dictionary, perspective is a particular way of considering something [19]. In photography, perspective refers to the dimension of objects and the spatial relationship between them. It also relates to the position of the human eye in relation to the objects in an image [20]. Changing focal length changes perspective (of course, focal length is not the only way to change perspective). In equally framed photos taken with wider-angle lenses, objects seem to be farther apart than in the case of longer-distance lenses; background is less defined (more blurred) when using telephotos. The *bokeh* effect, often seen in portraits, is that where the subject is sharp in focus and the background is highly blurred; this is achieved using a long telephoto lens and a short distance from the subject to the camera (the background "disappears" in the form of a blurry "backdrop").

The smaller the focal length is, the wider the angle of view. The focal length of the lens also affects the relative size of the image of the photographed object. One of the most important characteristics of the lens is its effect on the perspectives (e.g., changes in angle of view and depth of field). Wide angles increase the angle of view, while telephoto lenses reduce it, although many could argue that a bigger focal length decreases depth of field, *for the same photo frame* the depth of field is about the same with a wide-angle than with a telephoto lens (Fig. 10.17). What really changes perspective is the distance from the subject; using a lens with a different focal length compensates for being at a different distance from the subject.

Fig. 10.17 Effect of focal length on DoF. (Photography by Mayur Davda. All rights reserved) [21]

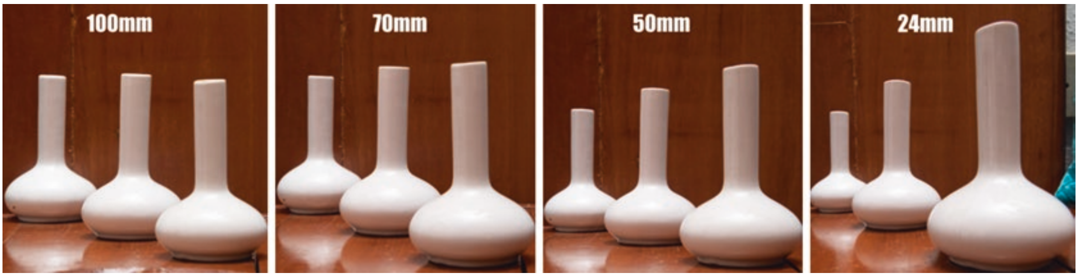


Fig. 10.18 Effect of focal length on image perspective. (Photography by Mayur Davda. All rights reserved) [23]

Considering images that are equally framed, the focal length is an indicator of distance from the subject [22]. In Fig. 10.18 all four images are framed alike but they have a different perspective; what changes from one photo to the next is the distance from the subject to the camera and consequently the lens' focal length used to maintain the same photo frame. The apparent separation between objects is higher for wide angles and the contrary for telephotos.

10.3.11 Filters

Filters are treated in detail in another chapter of this book (Chap. 11). Nevertheless, it's worth mentioning here two filters that should be part of the basic equipment of a conscious photographer. The polarizing filter can cut undesired reflections, like those arising from glass windows or still water surface. The neutral density (ND) filter blocks out light allowing you to extend exposure times. There are adjustable ND filters that commonly can reduce exposure from 2 to 8 stops. They are more practical than the fixed reduction NDs that have to be changed with every desired change in reduced exposure. In situations of too much light where for DoF considerations a big aperture is desirable, reducing exposure by using a ND filter can be an option. Here, some image quality may be lost, so a good-quality ND filter is recommended. Parallel polarized light will enhanced surface details while in cross-polarized wrinkles and surface detail disappear and vascular and pigmented lesions are enhanced.

10.4 The Exposure Triangle: ISO, Aperture, and Speed

Getting the exposure right is the most fundamental aspect of photography. Exposure is about letting the right amount of light reach the camera sensor. The contributing factors to exposure (exposure factors) are shutter speed, lens aperture (f-number), and sensor sensitivity (ISO). The combination of the three exposure factors gives what is called an exposure value (EV). There are

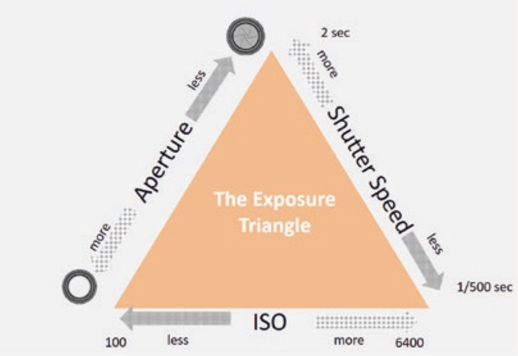


Fig. 10.19 The exposure triangle

many possible combinations of the three exposure factors to get the same EV. Welcome to the famous exposure triangle (Fig. 10.19)!

10.4.1 Exposure Value (EV) and Stops

Automatic cameras adjust themselves to get the best exposure, by giving the possibility to change the lens aperture, the shutter speed, and the sensor sensitivity. Mastering exposure is about balancing the three exposure parameters so the photo looks good, from depth of field to sharpness [23]. Mastering exposure is perhaps the core skill for good photography.

A *stop* is the change in exposure value that relates to doubling or halving the amount of light received by the sensor. An increase of one stop in exposure makes the sensor capture twice as much light as on the previous shot. A stop is a doubling or a halving of exposure, no matter which parameter in the exposure triangle is adjusted. For constant scene brightness, doubling the aperture area (one f-number or f-stop), halving the shutter speed (doubling the time open), or using a film twice as sensitive (doubling ISO) has the same effect on the exposed image.

When talking about exposure, an EV step is equal to a one-stop adjustment in any of the three exposure factors. −1EV means to decrease exposure by one stop; +1EV means to increase it by one stop. The exposure triangle gives a practical way to handle EV steps and exposure factor stops.

Stops are a great way to easily compare combinations of the three exposure factors. One can play around with the exposure factors while maintaining the same exposure value, bearing in mind that each factor change will have an impact on the final image that could or could not be desirable.

10.4.2 ISO (Sensor Sensitivity)

ISO refers to the sensitivity of the camera sensor to the incoming light, the same way that occurred in former film cameras with regard to ASA numbers. Some argue than ISO is not the sensitivity of the sensor but the digital adjustment made to the sensor in order to capture more or less light [24]. From our perspective, it is better to stick to the widely accepted understanding of ISO as sensor sensitivity. ISO are the initials of the International Organization of Standardization, an independent, non-governmental international organization, headquartered in Switzerland, with a membership of 164 national standard bodies. The ISO has issued tens of thousands of standards covering almost every industry: from management systems to medical devises to camera sensor sensitivity.

One of the great advantages of digital cameras is avoiding changing the film to get different sensitivity to light (in the old days you were stuck with whatever film speed you had chosen until the end of the roll) they allow to easily—even automatically—change ISO for each individual shot, as well as setting very high sensitivities reaching hundreds of thousands or in some cameras millions of ISO numbers (Nikon D5 low-light camera can shoot at ISO 3,280,000), something never reached by film (800 ISO was the standard high ISO film although some faster professional films could be “push processed” with the aid of some lab processing techniques to a few thousands ISO equivalent numbers [25]).

ISO numbers in the range 100–12,800 are considered typical for digital cameras although high-end cameras allow ISO numbers as low as 50 or as high as 204,800 or 409,600. Base ISO is the lowest ISO number in your camera. When possible, stick to your base ISO for best image quality; a lower ISO will give you less grain, better color, and wider dynamic range. In low light conditions or when a fast shutter speed is needed or when using a small aperture to get deeper DoF, it would be necessary to raise ISO. When brighter images are needed, it is best to raise the camera's ISO before shooting than brightening the image with post-processing software (it is much better to use a ISO 800 than ISO 100 and then brighten up the image with Lightroom software; the artificially brightened image will carry much more grain). Cameras with larger sensors (and also bigger pixels) allow for quite a large increase in ISO before significantly impacting image quality. If you have a DSLR camera or CSC, do not be afraid to experiment with larger ISO settings when needed. If you are using artificial light, you can get away with low ISO.

Today's top APS-C sensor cameras can capture little noise in dim light at ISO 3200+; thus if looking for a more affordable camera than full-frame, APS-C's cameras could be adequate for most applications in medical photography. Full-frame cameras cost more, are bulkier, and are only needed to do regular shots in dim light at ISO 6400+ or for printing images bigger than 2–3 ft in size. For situations with poor light or where a very high speed is needed, such as action indoor or night photography, full-frame is undoubtedly the better option.

ISO settings come in standard increments of 1 stop. For example, switching from ISO 100 to ISO 200 doubles the sensor's sensitivity, producing a 1 stop increase. Moving from ISO 400 to ISO 200 is a 1 stop decrease (Fig. 10.20).

ISO not only changes exposure; it also affects image quality. Increasing the ISO number also increases image's noise and loss if detail; the photo becomes "grainy" (the grain you could see in film photography is associated today with a vintage look like that in Fig. 10.21). When shooting JPEG at high ISO, the camera normally tends to apply noise reduction adding some blur to the image at the expense of detail. If you want to keep details in your image, it is best to adjust down your camera's noise reduction setting. Applying noise reduction in post-production tends to yield better details than when applying it in-camera.

In summary, high ISO numbers allow you shoot under low-light conditions, use faster shutter speeds, or obtain deeper depths of field (small aperture) but at the cost of more noise and loss of detail.

10.4.3 Aperture (Diaphragm)

Aperture: it's a hole! It's the opening of the diaphragm (Fig. 10.22) to allow the passage of light. The diaphragm is constructed from opaque thin blades than can slide over each other to change the opening (aperture) left at its center in a similar way to the iris. The diaphragm's center is aligned with the optical axis of the lens system. Other things remaining unchanged, opening the diaphragm causes more light entering the camera (Fig. 10.23).

An aperture stop is not doubling or halving the f-number; it is doubling or halving the area of the aperture pupil (effective aperture of the dia-

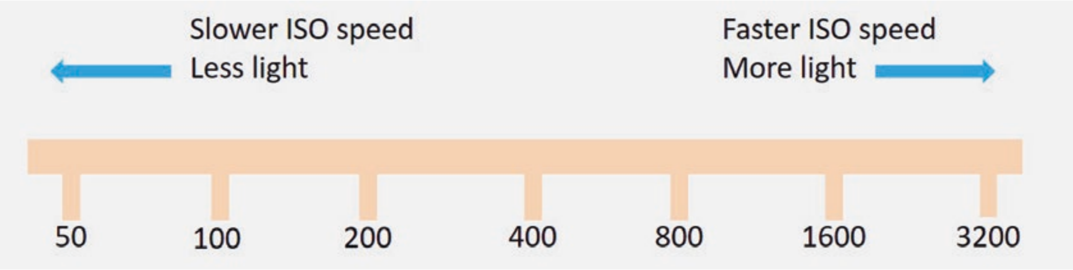


Fig. 10.20 Stops in sensor sensitivity (ISO)

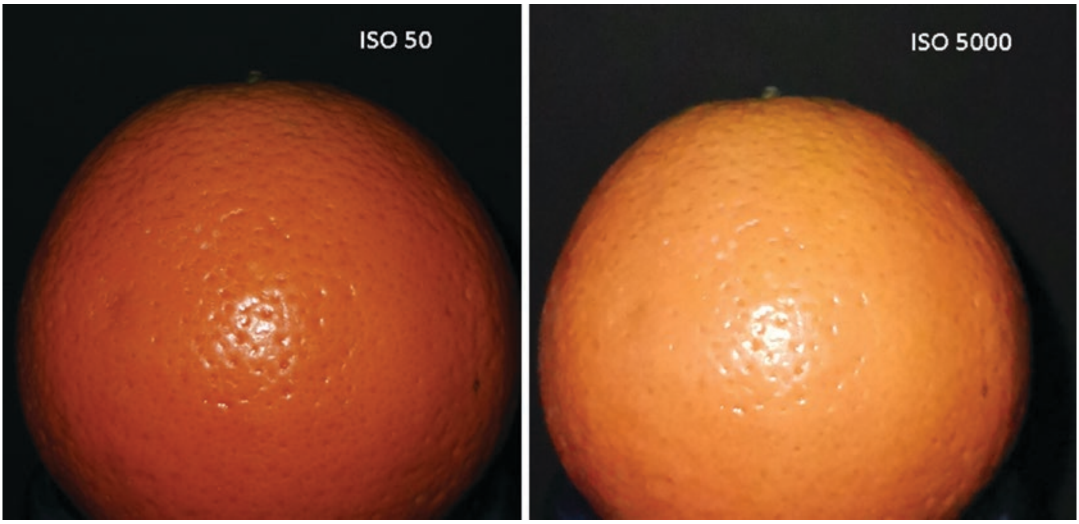


Fig. 10.21 Effect of ISO setting on grain. The image of the orange on the left shows more details. The one on the right is more grainy and details are less obvious [26]

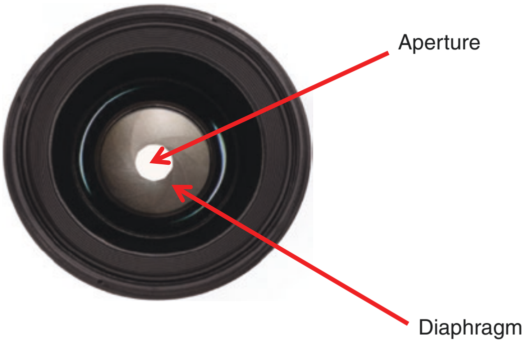


Fig. 10.22 Aperture: it's a…hole!

phragm), thus doubling or halving the incoming light inside the camera. An aperture stop is obtained by multiplying or dividing the f-number by 1.41 ($\sqrt{2}$). Doubling the aperture area equates increasing the circle diameter of the open shutter by $\sqrt{2}$ (see diaphragm apertures for standard f-stops in Fig. 10.24).

If a change of 1 stop in aperture makes the photo too dark, one can make it lighter either by reducing shutter speed 1 stop or alternatively doubling the sensitivity of the sensor by increasing the ISO setting by 1 stop (Fig. 10.25). Opening the diaphragm (increasing aperture) will reduce depth of field, reducing speed can bring blur, and increasing ISO will give more grain. When playing around with the exposure triangle, the photographer has to decide which way to go depending on the desired results.

In a similar way as with shutter speed, most cameras allow the user to change aperture in 1/3 stop increments (fractional stops).

10.4.3.1 Depth of Field (DoF)

Depth of field (DoF) is the distance zone within your photograph that appears sharp in focus from front to back. As a rule of thumb, one third of DoF is in front of the focus point; the other two thirds are behind it. Some images have a "thin" or "shallow" depth of field, where the background is completely out of focus. Other images have a "large" or "deep" depth of field, where both the foreground and background are sharp (Fig. 10.26).

The focus zone can be small (shallow DoF) or large (deep DoF), being diaphragm aperture (f-stop) its main affecting factor. Other DoF-affecting factors are the distance from subject to camera and the focal length of the lens.

In medical photography a deep DoF is a must. In a photograph of a patient's face taken with a shallow depth of field focusing the nose, probably the ears will be out of focus (Fig. 10.27).

The lower the f-number, the shallower the DoF. Likewise, the higher the f-number, the deeper the DoF. For example, setting of an f/4 will produce a shallow DoF, while f/11 will pro-

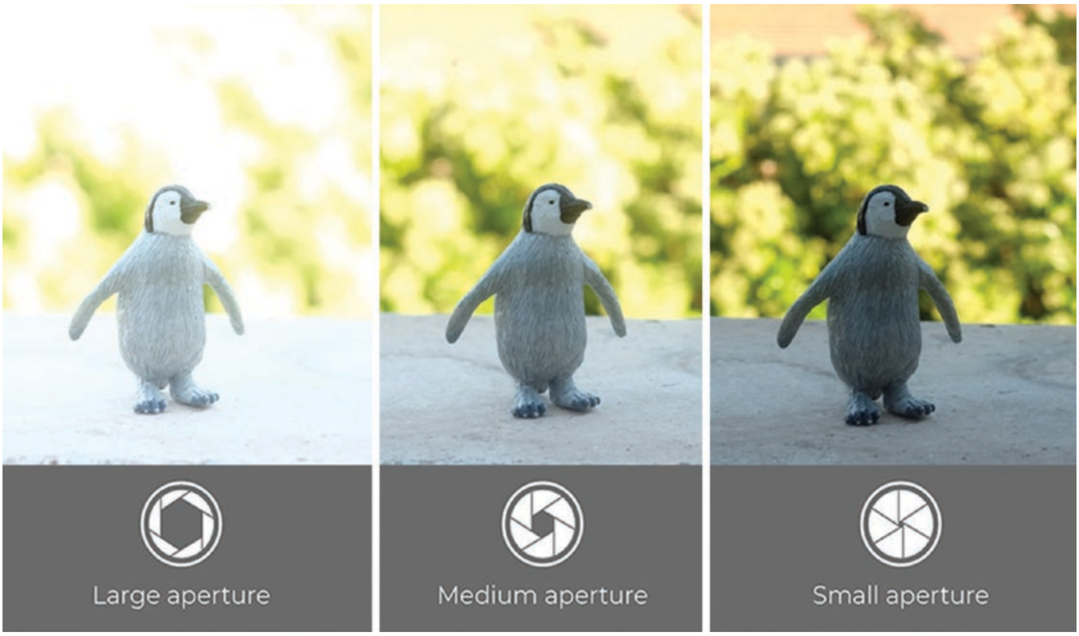


Fig. 10.23 Effect of aperture on exposure [27]

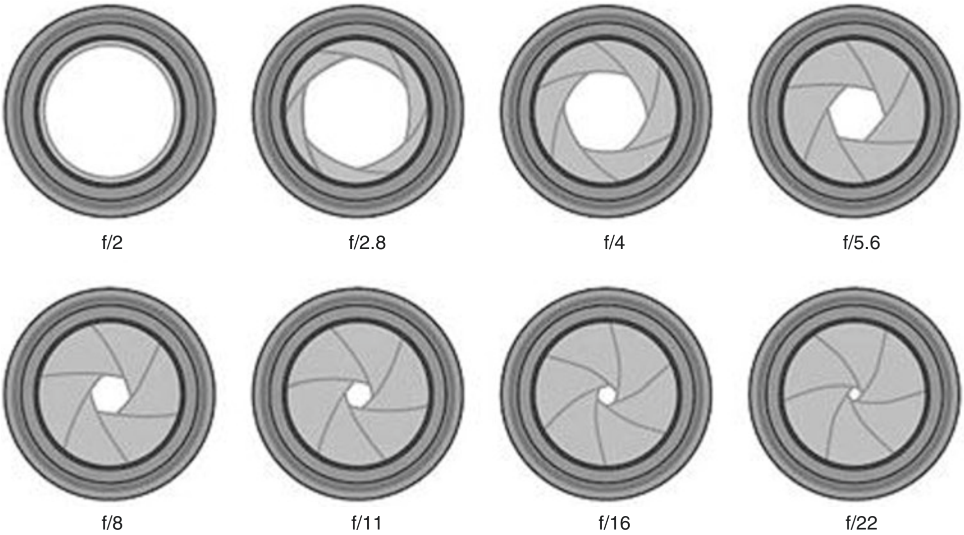


Fig. 10.24 Diaphragm aperture for different f-stops

duce a deeper DoF (f/11 aperture is 3 stops smaller than f/4) (Figs. 10.28 and 10.29).

DoF is also affected by the distance to the subject: the closer we are to the focused subject, the shallower the DoF. Therefore, one way to increase DoF is to move away from the subject (Fig. 10.30).

Similarly, if the photo is not reframed (no frame adjustment by changing camera position is done between shots; the distance to the subject does not change and consequently the framing of different shots changes with the angle of view of the lens), the longer the focal length, the shallower the DoF. Therefore, one can increase DoF by using a

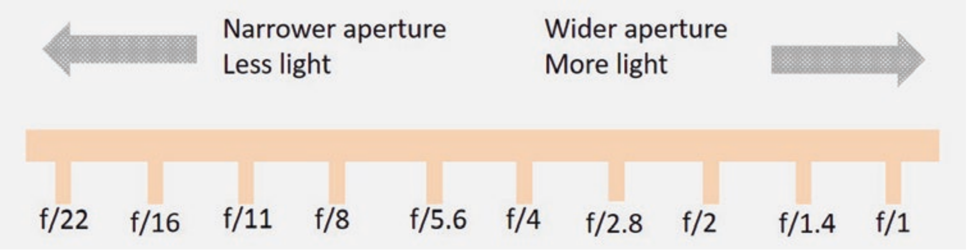


Fig. 10.25 Stops in diaphragm's aperture (f-numbers)

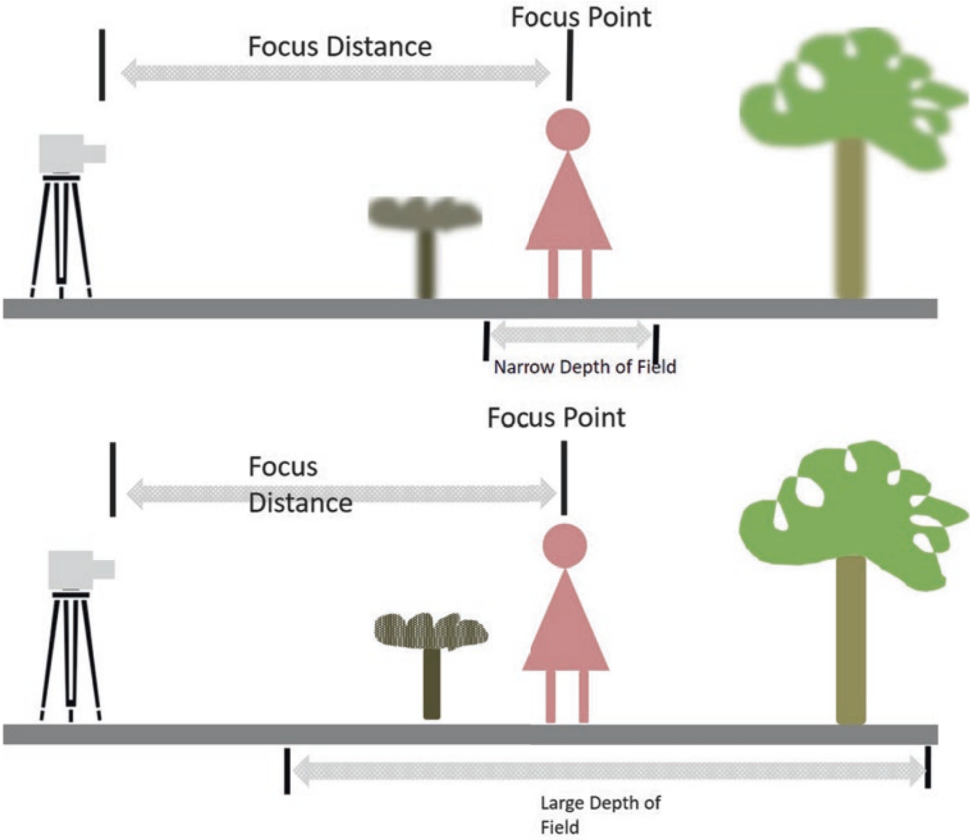


Fig. 10.26 Depth of field is the distance zone in sharp focus [28]

shorter telephoto lens (Fig. 10.31), but keeping in mind that if reframing to maintain equal frame DoF will remain almost unchanged [30].

The effects in DoF from changes in aperture, distance to subject, and focal length are summarized in Table 10.5.

Deep DoF is of particular importance for medical photography, for example, in close-up photos of a patient's body parts or macro photography of skin lesions. The objective of the medical photographer is to capture with sharpness all the subject's details.

10.4.4 Shutter Speed

The shutter (Fig. 10.1) is that piece of equipment that in most SRL cameras' body "opens" the passage of light for a pre-chosen period of time (exposure time or shutter speed) so the sensor can receive light with the image information. Although it is beyond the scope of this chapter to analyze the different shutter constructions, we will say a word on the common two-curtain shutter. The shutter has two curtains that move vertically from top to bottom to expose the sensor to light for a pre-chosen time. At the beginning of the cycle, both curtains are at the top, closing the entrance of light to the sensor. As the first curtain goes down, the light hits the sensor; then, the second curtain drops down closing the shutter opening, thus ending the exposure time. The time the shutter remains open can be adjusted to control the time exposure of the sensor. Once the set time has elapsed, the shutter closes back. The first curtain opens the shutter and the second one closes it.

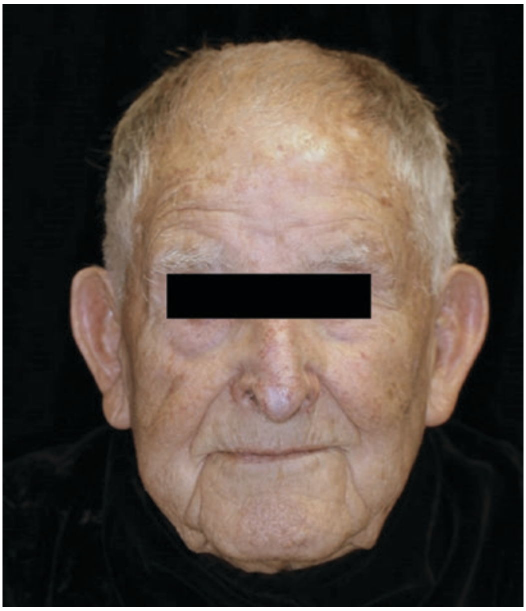


Fig. 10.27 In portraits, a too shallow DoF prevents all the face details to be sharp in focus

The time a shutter remains open (exposure time) is referred to as shutter speed. The reciprocal of exposure time expressed in seconds (or fractions of seconds) is used to determine shutter speed stops. For example, a 100 shutter speed mark means a 1/100 s exposure time.

In shutter speed terms, a stop is when doubling or halving the shutter speed setting, thus allowing for doubling or halving the light hitting the sensor (see shutter stops in Fig. 10.32). For example, going from 1/60 to 1/30 lets in twice as much light, giving a 1 stop increase in exposure (+1 EV); on

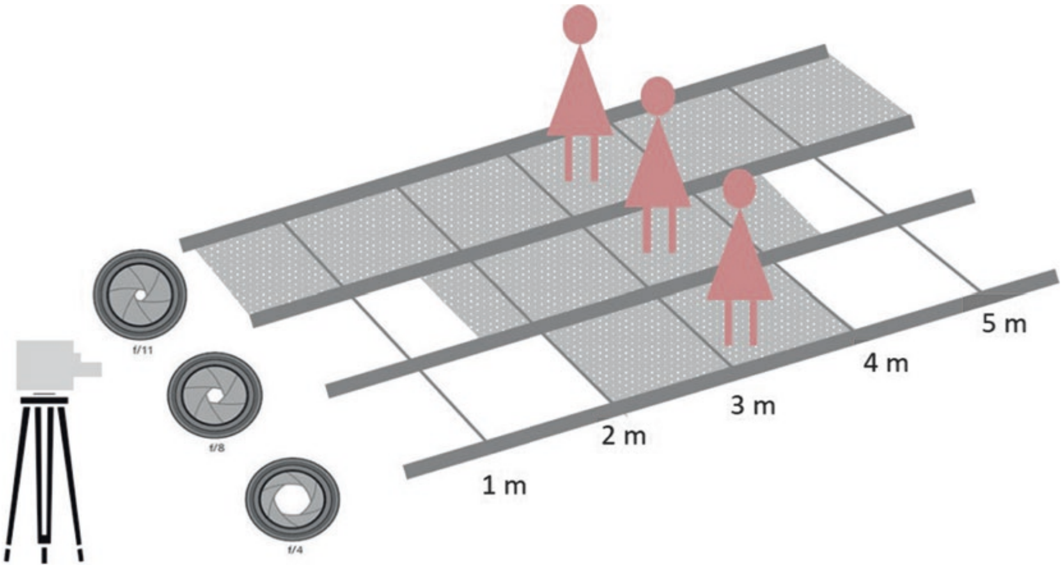


Fig. 10.28 Effect of aperture on DoF

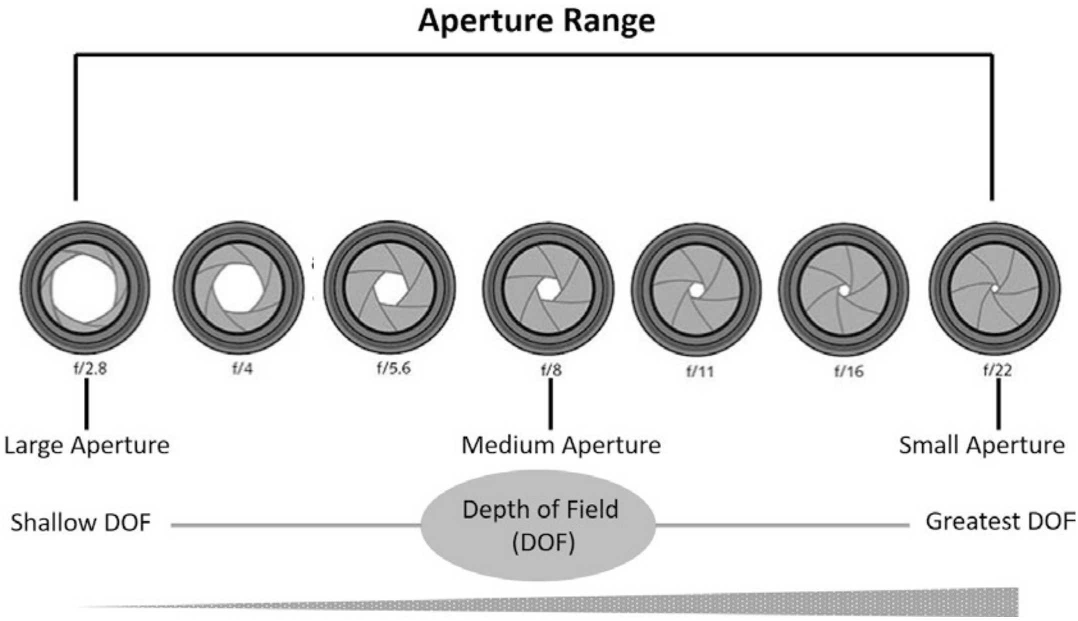


Fig. 10.29 Aperture and depth of field [29]

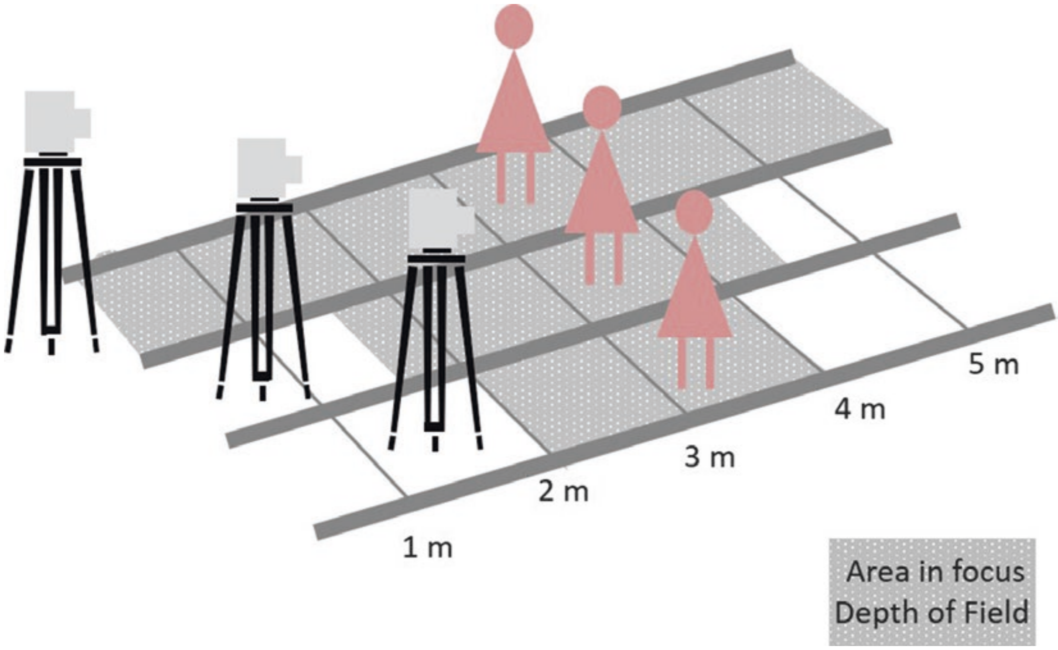


Fig. 10.30 Effect of distance to subject on DoF

the other hand, going from 1/30 to 1/60 would give a 1 stop decrease (−1 EV). Most cameras today allow for shutter speed fractional-stop increments of 1/3 of an f-stop (1/3 EV), so three clicks will increase or decrease exposure by 1 stop.

When photographing moving objects, shutter speed can be the key factor: if shutter speed is too low, image will appear blurred. In the case of still objects, shutter speed can go as low as needed to get the right exposure.

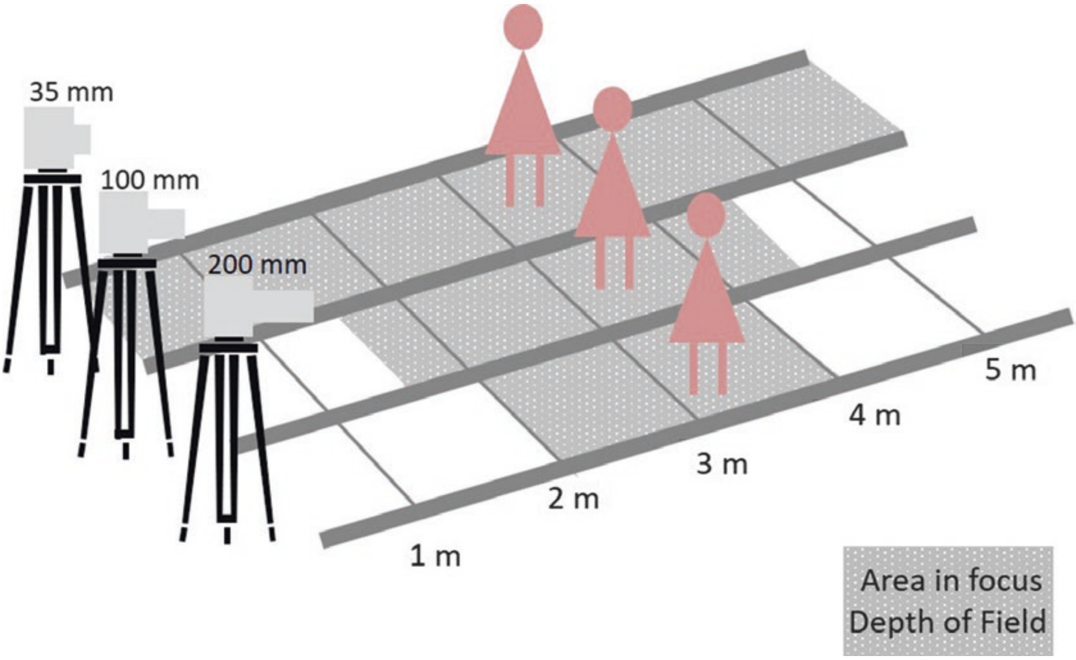


Fig. 10.31 Effect of focal length on DoF

Table 10.5 Sense of change in DoF by changes in affecting factors

Increase in	Effect on DoF	Decrease in	Effect on DoF
f-number	↑	f-number	↓
Distance to subject	↑	Distance to subject	↓
Focal length	↓	Focal length	↑

In portrait medical photography, shutter speed is usually set at 1/60. Most shutters have a flash synchronization switch to trigger a flash if connected, as most medical photography is taken with flash.

In conclusion, in portrait medical photography we need low ISO, shutter speeds around 1/60, and small apertures for the deepest depth of field (Table 10.6).

Blooming is when the light source gets into the framed scene and light streaks out from the light source producing star-like reflections that can overexpose and distort a good portion of the frame. It happens when taking photos that include the sun, a lamp, or chrome-shining surfaces. Blooming, a very much exploited effect in wedding photography, is an undesirable effect when doing medical photography. Just keep away from any direct light source or shiny surfaces that could get into your frame.

10.5 Histogram and Correct Exposure

When an image has a correct exposure value, all individual zones within the photo have the right exposure. An overexposed photo has too much light in the photo; an underexposed photo there is not enough light to reveal the details of the scene. Both overexposed and underexposed photos produce loss of detail and loss of information about the subject (Fig. 10.33a).

A histogram is a tool to analyze the correct exposure of a photo. All DSLR cameras and CSC allow you to see on the LCD screen the histogram of each image. The histogram is a graphical representation of the tones in the image (the vertical axis represents the amount of pixels with that particular tone; tones are ordered from darker to the left to lighter to the right). The very dark

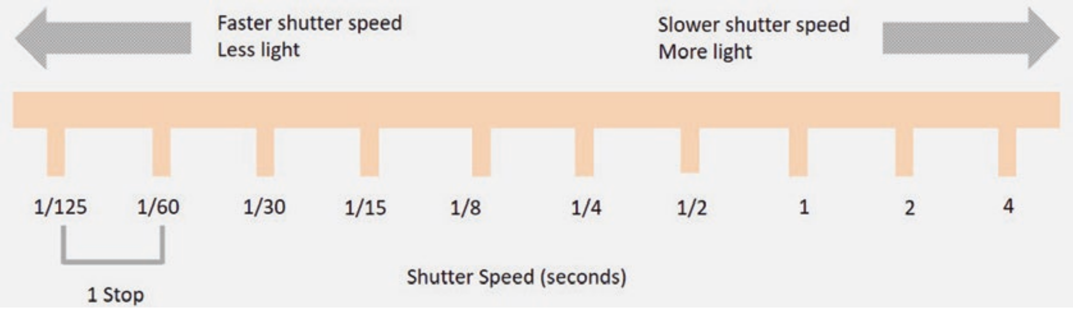


Fig. 10.32 Stops in shutter speed

Table 10.6 Effect of individual changes on exposure factors

Exposure factor	Effect
Shutter speed	If low, photo may be blurred due to camera/subject movement
Aperture	If wide (low f-stop), depth-of-field compresses If narrow (high f-stop), depth-of-field expands
Sensibility (ISO)	If high, more noise for a grainy look and loss of sharpness

tones are quantified at the extreme left part of the diagram and the very light tones at the extreme right. In between, the dark, medium, and light tones arranged from darker in the left to lighter in the right (see Fig. 10.34). The ideal histogram (correct exposure) is that with tonal readings more evenly spread within the graph. A histogram biased to the left indicates underexposure (too many dark areas in the photo), and one biased to the right indicates overexposure (too much white) (see Fig. 10.33b).

10.6 Exposure Fine-Tuning

DLSRs and CSCs have an exposure compensation control when working on P, S, or A exposure modes which allows the photographer to manually adjust the EV setting chosen by the camera by fractions of EV steps (Fig. 10.35). If the image is too dark, a positive compensation will increase exposure brightening the image; a negative compensation will darken it. After selecting the exposure mode (e.g., program mode), take a test shot. If the image exposure is not correct, you can compensate for EV using the exposure compensation ring (in aperture mode the camera will adjust shutter speed; in shutter priority mode it will adjust the aperture; and in Program mode it will adjust aperture and shutter speed).

10.7 Focusing

After exposure, focusing is perhaps the most important factor for good photography. Framing or colors may be not optimal, but a photograph can still be acceptable if it is sharp on focus. Of course, for medical applications, specifically for dermatology where tumors can be identified by its patterns and colors, focus is necessary but may be not sufficient.

Manual focus can be the best option for photographing close-ups, thus allowing for a close control over the point where you want the lens to be focused.

Autofocus (AF) modes allow for automatic adjustment of the focus by the camera. By pressing the shutter-release button halfway down, the camera will adjust the focus on the focus point(s) previously set. When the shutter-release button is pressed all the way down, the photo is taken using the focus already set. Focus point(s) can be pre-adjusted by the user. In one-shot (or single-shot) AF mode, once the focus is locked the focus will be maintained invariable. In continuous AF mode, after you lock the focus the camera will continue to adjust focus automatically in order to care for a moving subject. In Auto AF mode (AF-A in some cameras), the camera will choose automatically to use either one-shot AF or auto AF, depending on the movement of the subject.

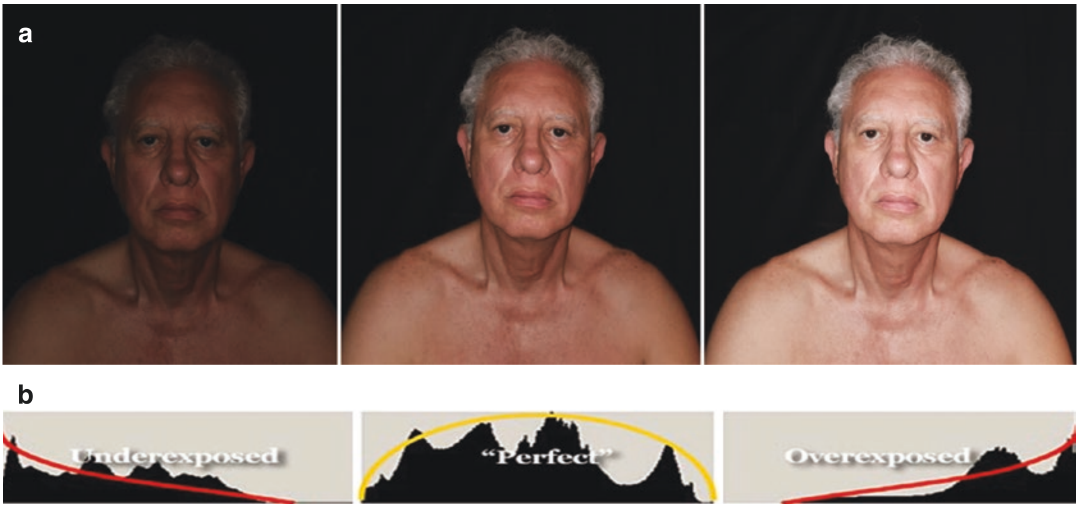


Fig. 10.33 (**a**) Both underexposed (left) and overexposed images (right) show detail loss when compared to the central image. (**b**) The histogram shows the location of the largest number of pixels that share the same brightness. The ideal curve is the one in the center

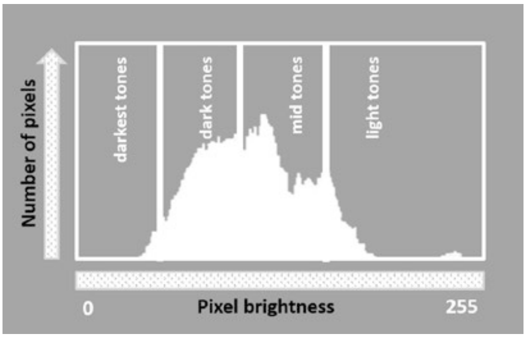


Fig. 10.34 A histogram shows the number of pixels that share the same brightness level

Instead of adjusting AF points for every photo, a fast alternative is to set the central AF point while using one-shot AF mode. Then, point at your subject where you want to focus and press the shutter-release button halfway down to focus. Then, while keeping the shutter halfway to maintain focus, reframe your shot and press the shutter-release button fully to take the photo.

10.8 Holding a Camera

Aside from focusing holding your camera steady is also paramount for obtaining sharp images (Fig. 10.36). In case you are not using a tripod, the position of your body, particularly hands and arms can make the difference between a good and an inacceptable photo. Stand in a steady position, facing your subject. Hold the camera with your right hand with your finger close to the shutter-release button and your fingers around the camera's grip. Support the lens with your left hand so you can control zoom and focus rings. Keep your arms locked into your sides. Press the shutter release button slowly. Shot at the end of your exhale.

For many photographers a tripod is indispensable. Maybe the rule here is that if there is a disadvantage in holding on to the camera then consider using a tripod. A tripod will be from advisable to indispensable when doing portraits such as clinical photos of patient's face, using macros such as photos of tumors, under poor light conditions, under small aperture and low ISO conditions, under long exposure conditions, and when using long telephoto lenses (for a given shutter speed, it is common for most people to hold steady the camera when the focal length of the lens is not bigger than the inverse of the shutter speed; e.g. for a 100 mm telephoto it is safe to not use a tripod for shutter speeds of 1/100 s and faster [33]).

Fig. 10.35 Exposure compensation controls [31]

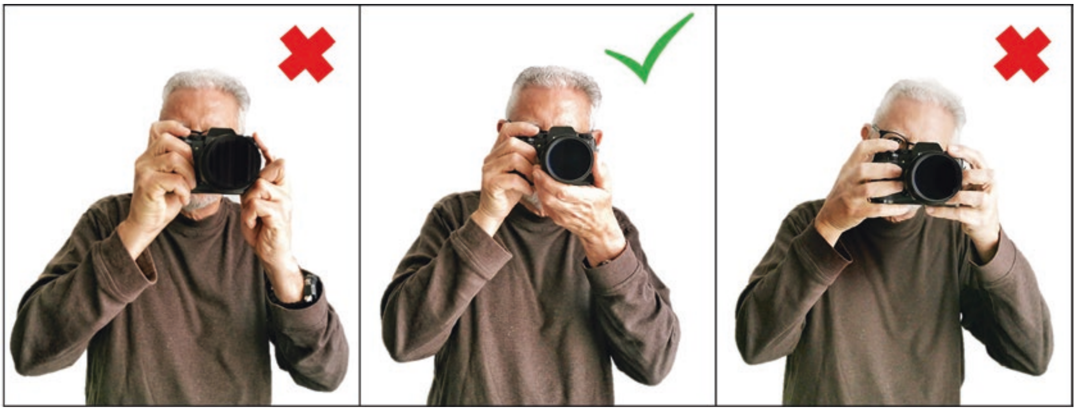


Fig. 10.36 How to hold a camera steady to avoid blurry images [32]

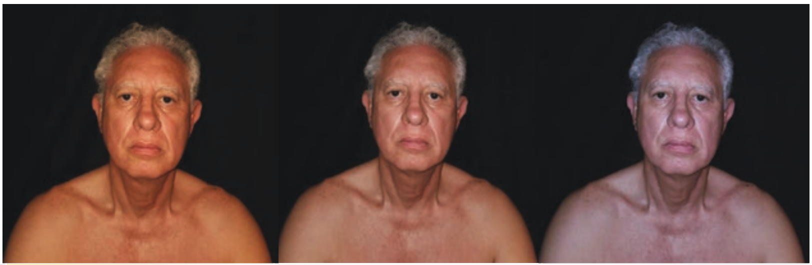
10.9 Color of Light and White Balance

Every source of light has a predominant color that in general is not neutral. When shooting a subject, its natural colors become affected by the color of the source of light. Light reflected by snowy mountains shifts toward blue tones, whereas light from sunny deserts is more to the orange-yellow part of the spectrum. Different artificial sources of light also have their own color differences. The color of light can be measured by Kelvin degrees. The color temperature of a light source is the temperature of an ideal black-body that radiates light of a color comparable to that of the light source [34]. Daylight has a nominal color temperature of 5500 K and it's normal for artificial light bulb manufacturers to call Daylight the color range 4600–6500 K, Warm White the range 2000–3000 K, and Cool White the range 3100–4500 K (Fig. 10.38) [35].

To capture natural colors of the subject, the photographer has to adjust the camera for the color of light the subject is illuminated by. This adjustment is called White Balance (WB) because what the photographer does is adjusting the whites in the image trying to replicate the whites in the natural subject (Fig. 10.37).

In the camera, the WB can be set to automatic (AUTO or AWB, the camera assesses the scene and sets the white balance accordingly), to a particular ambience light mode (Daylight, Cloudy, Shade, Tungsten, Fluorescent, or Flash) or Custom when the subject is illuminated by more than one light source and it becomes difficult to choose one particular WB mode.

To manually set the right color temperature for Custom WB mode, it is common to use a cali-



Color Temperature (Kelvin)	2000 K-3000K	3100-4500K	4600K-6500K
Light Appearence	Warm White	Cool white	Daylight

Fig. 10.37 Color temperature of artificial light bulbs [36]

Fig. 10.38 Dial modes in most popular DSLRs and CSCs. On the right, a Nikon dial (Courtesy of © Nikon Europe B.V, 2019, All rights reserved); on the left, a Canon dial. (Courtesy of © Canon Inc., All rights reserved)

brated gray card, although there are other methods such as the ExpoDisc White Balance Filter, the cheap JCC WB-F1 Filter or using a color meter such as the Illuminati IM100 (the last one—also a light meter—is controlled by a smartphone app via Bluetooth).

White balance adjustment is paramount for applications such as medical photography, where, for example, the exact reproduction of the natural colors of a patient's skin or lesion is mandatory for the correct diagnosis and monitoring of treatment.

10.10 Camera Modes

Digital cameras have internal software and hardware that allow automat adjustment for perfect exposure, focusing, white balance, and flash utilization or they let the photographer to make all adjustments manually. Although going for all manual requires a lot of knowledge and experience, scene and exposure modes can be of great help, even to seasoned photographers. Scene and exposure modes can be selected by using the mode dial. Figure 10.38 shows typical mode dials found in Nikon or Canon cameras.

Table 10.7 Scene modes [36]

Scene mode	Mode description
Portrait	Wide aperture to keep background elements out of focus. Color and contrast to produce natural-looking skin colors. Automatic built-in flash in low-light situations
Landscape	Small aperture for deep DoF. Color intensified to add vibrancy to green and blues. Flash is switched off
Child	Wide aperture but with faster speed than Portrait. Colors are more vibrant than Portrait
Sports	Fast shutter speed to freeze action, usually accompanied by a wide aperture. ISO will be increased to do the job, even at the expense of noise. Flash is switched off
Macro/ close-up	Small aperture to easy focusing. Colors are kept neutral. Automatic flash

10.10.1 Scene Modes

Camera manufacturers include in their equipment scene modes intended to simplify camera adjustment for particular tasks. There may be many scene modes, but the more common ones are those listed in Table 10.7. For medical photography, Portrait and Macro/Close-up modes can be of particular interest; they both keep colors neutral. Portrait mode sets a wide aperture to concentrate focus in the main subject (e.g., a patient's face), while Close-up mode sets a small aperture to increase DoF and thus get into focus a more ample depth of the subject (e.g., a skin mole or tumor).

10.10.2 Exposure Modes

As it happens with scene modes, different camera manufacturers include different exposure modes in their equipment. As opposed to scene modes, in exposure modes the photographer controls the exposure of the photo, regardless of the scene that she is shooting. The more common exposure modes found in today's DSRLs and CSCs are listed in Table 10.8. The aperture mode can be of special interest to medical photography where a deep depth of field is desirable. Both scene and exposure modes can be selected in the Mode dial generally located on the top section of the camera body.

Table 10.8 Exposure modes [37]

Exposure mode	Mode description
AUTO	In this mode, the camera takes all decisions. Flash is also automatically controlled. The photographer has to only point and shot
Program (P)	The camera will automatically control aperture and shutter speed, leaving the photographer the option to control ISO, white-balance, and other options
Shutter Priority (S/Tv)	Preferred shutter speed is chosen by photographer, and the camera selects the aperture setting for best overall exposure. Other options open to selection by the photographer. A good choice for sport photography
Aperture Priority (A/Av)	Similar to Shutter Priority, but in this case aperture is chosen by photographer and speed is adjusted automatically by the camera for best overall exposure. Other options open to selection by the photographer. A good choice to control depth-of-field
Manual (M)	The camera will suggest good exposure settings, but all adjustments remain in the hands of the photographer

10.11 Bracketing

In bracketing, the camera takes the same scene more than once changing exposure settings each time so you can later choose the photo you prefer or combine them digitally to get just the best information out of every one. In a scene with a high dynamic range (the scene has zones of strong light and zones of deep shadows), you can shot several photos of the subject, each one exposure optimized for a different zone of the scene.

Automatic exposure bracketing (AEB) is a feature of your camera that makes it take three photos with every click: one photo too bright, one photo just right, and one photo a bit darker. Exposure values are changed automatically by the camera.

Fig. 10.39 Effect of HDR usage. Left to right: original image, Lite HDR adjustment, strong HDR adjustment [37]

10.12 Dynamic Range and High Dynamic Range (HDR) Imaging

The dynamic range of a scene is the brightness range or contrast, from the darkest shadow to the brightest light as captured and reproduced by a piece of equipment (camera, digital display, or printer). Cameras, graphical displays, and printers all have their own dynamic range. Also the human eye has its own dynamic range.

Every photographed scene has lighter and darker zones. One can talk about the dynamic range of the scene being photographed. But, one can also talk of dynamic range when referring to the range of lights and shadows in the digital image formed inside the camera. This second dynamic range is attributed to the technical characteristics of your camera, mainly the camera sensor. A scene with a high dynamic range (high contrast) has a lot of dark zones and a lot of lighter zones. On the contrary, a scene lit in such a way that it is neither too bright nor too dark is said to have a low dynamic range (low contrast) (Fig. 10.39).

One way to increase the dynamic range of a digital image (high dynamic range or HDR) is by taking a group of exposures and then digitally combining them together to get the best exposure for each zone of the scene. Dynamic range optimization can be done automatically by the camera. Different camera manufacturers use different names for dynamic range optimization such as Auto Lighting Optimizer (Canon), Active D-Lighting (Nikon), or D-Range Optimizer (Sony). Photo-editing software can also adjust for HDR. In HDR images the darks are a little darker and the lights are a little lighter. HDR increases contrast. In a portrait image HDR-corrected, wrinkles may appear deeper and other skin details more exaggerated. An HDR-corrected image could be useful to do some skin studies.

10.13 Stitching and Stacking

Images can be overlapped by stitching or by stacking.

10.13.1 Stitching

A family of overlapping images can be digitally “stitched” together to produce a panoramic or a high-resolution image. This feature is common in smartphones under Panorama mode. High-resolution digital maps and satellite photos are stitched together to get a high-definition seamless image of Earth. In medical photography, such as in total-body photography, the total-body image is the result of stitching together multiple photos of different parts of the body to produce a combined seamless image of the human body. This technique is used to study changes of skin lesions. Three-dimensional photography software, used by plastic surgeons and dermatologists, use stitching to seamlessly combine left, front, and right photos of patient's face. External (not in the camera) stitching software is normally used for geographical or medical applications.

10.13.2 Stacking

In scientific photography it is important that every bit of graphic information of the subject be sharp on focus. Blurred images prevent the best use of the subject information. For example, in clinical photographs of patient's head or limbs, DoF can be so shallow that valuable information gets lost. Also, in macro photography when registering images of lesions, even for small aperture settings, DoF can be very shallow. With the focus stacking technique, a group of images of the same scene is captured but with different focus points; by means of a digital program, the different photos are stacked, one on top of the other, keeping just the best focused zones of each one to build a new photo with everything in focus. The final result after stacking is a photo that is in sharp focus from foreground to background. Stacking is done in plenoptic cameras (see Chap. 31).

10.14 Lighting

Most medical photography is done with flash lights. DSLRs and CSCs come with a built-in flash and also a flash hot shoe where to clip an on-camera flash, a macro-ring-light or an external flash head with remote TLL (through-the-lens) metering control. By using a flash, one can get a constant amount of light, always of the same color temperature. Flash light has a color temperature similar to daylight. When using flash and due to its much higher intensity, dimmer ambience light becomes irrelevant; changes of light during the day will not affect the final outcome either. For the ideal exposure for flash portrait medical photography, the smallest ISO and aperture (biggest f-stop) can be left fixed, allowing the shutter speed to be adjusted no slower than 1/60 s.

In addition to the abovementioned advantages for using a flash, there are some important potential risks to keep in mind:

1. Washing out of images
2. Shadows' management: wrinkles tend to disappear, elevated lesions look flatter
3. Red eye or ring image reflected in the eyes

Washing out refers to the overexposed image obtained due to excess power of the flash. This can be managed in the same way as exposure can be fine-tuned to get the correct exposure; the intensity of the flash can also be adjusted down (flash compensation) from full flash by −1/2 or −1 stop.

Built-in flashes and to a lesser degree on-camera flashes tend to leave a bright washout (overexposed) central area. This is particularly noticeable in frontal face and in bold skull photography. In both cases, diffusers help to reduce shadows and to soften the light. There are commercially available diffusers like those in Fig. 10.40. Some "home-made" solutions to reduce flash intensity include covering the frontal part of the built-in or on-camera flash with translucent (onionskin) paper.

In a portrait photo, shadows in the face can hide details; backdrop shadows can be distracting. Shadows can be avoided when using soft natural light (in-camera flash may flatten your patient's face image with the consequential loss of detail), but then whites would have to be adjusted (white balance) to obtain natural colors. In flash photography diffusers softening of light helps reduce the shadows on the subject as well as those shadows created by the subject on the backdrop (Fig. 10.41).

Another way to deal with distracting background shadows is by separating the subject from the backdrop while shooting at a fast shutter speed; the shutter will be synchronized with the flash and will close before the flash light hits the background (the subject is well lit by the flash but

Fig. 10.40 Examples of flash diffusers. On the left, Gary Fong Lightsphere Collapsible with Speed Mount. (Courtesy of ©2018 Gary Fong, All rights reserved); on the right, FD-320 Universal Softbox for Portable Flash. (Courtesy of ©2020 Gradus Group LLC, All rights reserved)


Without diffuser

With diffuser

Fig. 10.41 Effect of flash diffuser on shadows (with permission of Canfield Co)

the background is dark because the flash light has not reached the background yet) (Fig. 10.42).

For better facial contouring, the color of backdrops used for medical portrait photography should be color contrast with the skin color of the patient. Black velvet backdrops do have the advantage of reduced reflections and shadows, but for photographing very dark-skinned patients (Fitzpatrick types V and VI) a blue or green non-glossy backdrop would do a better job.

Ideal lighting is studio lighting which will be covered in the chapter “Setting up a photographic studio” (Chap. 10). A summary on the advantages and disadvantages of natural, flash and the so-called “full spectrum bulbs” can be found in Table 10.9.

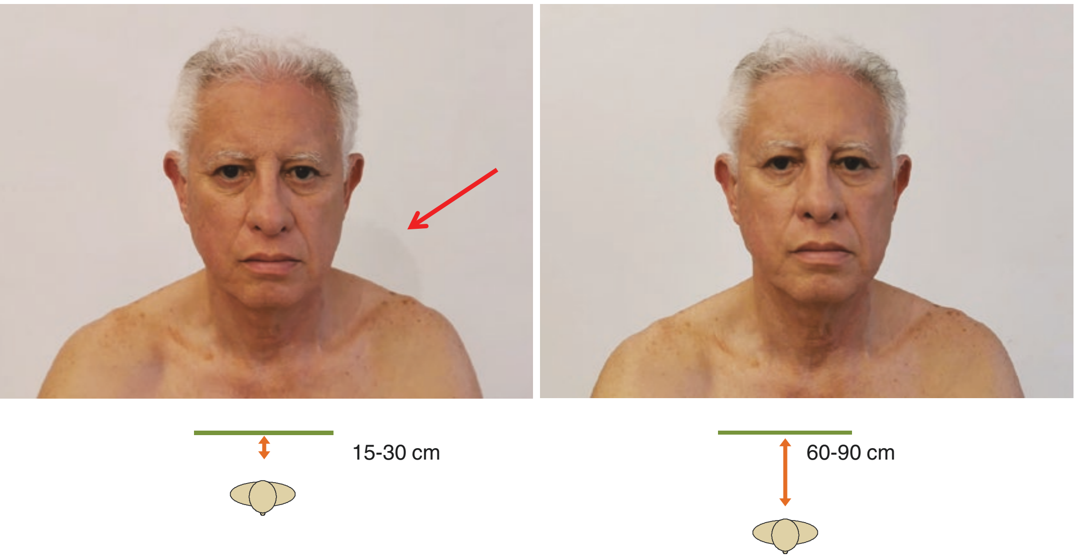


Fig. 10.42 Effect of backdrop distance behind subject. By separating the patient from the backdrop or wall, shadows disappear

Table 10.9 Advantages and disadvantages of light sources

	Natural	Flash	Full-spectrum bulbs
Advantages	Can be useful in close-up photography. It gives more information on depth. Especially relevant in tumor photography. Wrinkles and scars are best visualized	Light is identical at any time of the day As light is maintained, ISO, Aperture, and Speed can be maintained in ideal position	Light is identical at any time of the day
Disadvantages	It changes continuously during the day. Depending on the orientation: shadows are more visible	Tends to lighten skin color. Reduces contrast. Depending on the type of flash, adjustment and anatomical area: washing out or central brightness is possible	Not easily available

Red-eye reduction can be set on the camera and it is aim to avoid red eyes in a subject that is looking straight toward the camera. A pre-flash is lit before the main flash causing the subject's pupil to contract just before the shot.

Slow Sync. At night, with a dark and remote background, a fast flash will only lit a subject close to the camera; the surroundings will appear underexposed (some of this has been treated above in this section). A lot of background detail will be lost. A slower shutter speed in addition to firing the flash can solve the problem. Cameras have a slow sync adjustment to precisely do that. With the activation of slow sync the subject in the foreground and the background get well exposed.

First/Second Curtain Sync. The common shutter has two curtains that are activated sequentially one after the other: the first curtain goes down to open the shutter and then the second curtain goes down to close it. For photographing static subjects, the first curtain sync is the best; for moving subjects, the second curtain sync allows to capture the forward movement of the subject (a moving subject photographed with the first curtain sync will look as is going backward).

If shutter speed is too high as compared to flash speed, then part of the sensor will not be exposed; the image will be cut off, a black strip corresponding to the first shutter curtain will show in the photo. The sync speed is the fastest shutter speed that fully exposes the sensor to the flash light; it's around 1/200 s for most cameras. Never use shutter speeds faster than 1/200 when taking flash photos.

10.15 Conclusion

Once we have a good camera in our hands, we need to master some basic photographic concepts: exposure and its factors, focusing, white balance, and lightning. There is only one way to master these concepts: take many photographs! Experience is a very good teacher. Understanding how the camera works, experimenting, and studying yours and other's photos will help you improve your photographic skills. The broad brushstrokes in this chapter can be a first step in the wonderful and enriching journey into the complex and vast world of medical photography; we invite our readers to enjoy it, taking it with perseverance, patience, and passion, the three Ps for success.

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Equipment and Materials for Medical Photography

11

Ali Johnston, Paola Pasquali,
and Ramón Alberich-Carrasco

Contents

11.1 Introduction

The first question most people ask when they get into medical photography is: what type of camera and accessories do I need to use or buy? Given the high availability of cameras, lenses, and accessories in the market and the different objectives sought when shooting, it is extremely difficult, if not impossible, to make a one-size-fits-all recommendation. Each medical specialty will find a particular set of equipment with features that makes it best suited for their particular requirements. This chapter will deal with some basic knowledge on cameras, lenses, flashes, and other useful accessories to help make a start with the right foot on medical photography. Seasoned photographers will certainly need more in-depth information on photographic equipment. Here we will focus on digital photography and its use in detail (macro), portrait and full body. Special

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equipment (e.g., ophthalmology, dental, and endoscopy) will be dealt with in specific chapters.

11.2 Equipment

Selecting the right camera comes down to what type of photographs you want to take, in what context you are going to use them and how much you are willing to spend. Although not an easy task, getting the best equipment for the job right from the beginning should be the main objective for a medical photographer; that will save the frustration of making a non-negligible investment and then realizing that your pictures are not good enough for the purpose you took them for.

In this chapter we deal mainly with nonmedically specialized photographic equipment that may be appropriate for medical photography. In other sections of this book, we deal with photographic equipment specifically designed or adapted for medical needs.

The photographic equipment we describe is seen from the perspective of its potential use in medical photography. This section is not commercially biased. Suggestions are based on the authors' personal use, experience, and knowledge; any mention of brands is only done with the intention of helping the reader better understand the different options when choosing photographic equipment. As this chapter is written during the first part of year 2019, most of the models shown here reflect what the market offered at that time. It is impossible for a chapter on photographic equipment not to become obsolete in just a few years (or months!). As technology evolves, new models become available. It is to the reader to adapt the subjacent message of what makes a better medical photographic equipment to the upcoming models. Your first camera will probably not be your last one. You will upgrade into new models, change manufactures, and probably change technology. Just to say that the authors of this chapter are from the analogic era of photography! For those passionate for technology and for those that make use of technology just to improve the quality of people's lives (including their own), there is an exciting journey ahead of us. Let's go for it.

11.2.1 Cameras

Digital cameras can be classified into different types (Table 11.1):

- Basic compact
- Advanced compact (also called zoom compact)
- Bridge (also called super-zoom)
- Mirrorless (or compact system camera—CSC)
- Digital single-lens reflex (DSLR or dSLR)
- Medium format
- Adventure (action) cameras
- Instant cameras
- Smartphones

Maybe the types more relevant to the scope of this chapter are those with interchangeable lenses (DSLR and mirrorless cameras) and, of course, smartphones.

As technology is in constant evolution, the frenetic speed of change makes it impossible to recommend one camera brand over another; it even makes it difficult to set clear-cut definitions between camera types. The biggest brands are putting great effort in research and development and enhancing so much camera capabilities that different camera types are becoming to overlap in their feature offer. There are today compact cameras with features that in the past were only available in DSLR/CSC cameras, like 1-in. sensors, external flash connectivity, and RAW shooting.

Putting aside the traditional classification of cameras mentioned above, maybe the single most important feature that might allow classifying cameras is their sensor size and resolution (pixel size is paramount). As we explain in this and other chapters of this book, the final use of the image (either on a digital display or printed on paper) will demand a minimum sensor size and resolution. In this chapter we transit the traditional classification of cameras but highlight their sensor size and resolution as a key element.

Table 11.1 Types of cameras

Camera	Type	Advantages	Disadvantages
	Basic compact	• Small, light • Inexpensive • Easy to use • Auto mode • Liquid crystal display (LCD) • Many models with non-detachable zoom • Small sensor 10 MP range	• Fixed lens • Small storage capacity • Massive depth of field (all in focus) • No-flash regulation • Low image quality • Digital zoom • "Kids" cameras. Not recommended for medical photography
	Advanced compact	• Small, portable • Automatic and manual control • RAW and JPEG • Some models can attach external flash	• Fixed lens • Small sensor typically in the 1/2.3 range (5.64 crop; 20 MP) • All in focus can be a problem • Slow image processing • Lower-quality images
	Bridge/ super-zoom	• Compact • Good-quality image • Macro • In some: ring flash can be adapted • RAW and JPEG • Automatic and manual shooting • Bigger pixel size than advanced compact	• Fixed zoom lens • Sensor typically in the 1 in. range (2.7 crop; 20 MP)
	CSC/ mirrorless	• Interchangeable lenses • Full-frame (36 × 24 mm; 1.0 crop) to four-third (17.3 × 13 mm; 2.0 crop; 24–46 MP) sensor can render high-quality photos. Smaller than comparable DSLRs • RAW and JPEG • Full control settings • Wide range of lenses and accessories • CSCs are substituting DSLRs	• Only some models have optical viewfinder • (OVF) (e.g., Fujifilm) • Can be more expensive than low-end DSLRs
	DSLR	• Interchangeable lenses • Full-frame (36 × 24 mm; 1.0 crop) to four-third (17.3 × 13 mm; 2.0 crop; 24–46 MP) sensor can render high-quality photos • The traditional SLR look-and-feel • RAW and JPEG • Full control settings • Wide range of lenses and accessories	• Heavier, bulkier, and more expensive than CSCs • Once the reign Nikon and Canon, DSLRs have been substituted by CSCs from many brands

(continued)

Table 11.1 (continued)

Camera	Type	Advantages	Disadvantages
	Medium format	• Allow big cropping/ magnification • Leica ProFormat (30 × 45 mm) 60 MP sensor • Fujifilm G format (43.8 × 32.9 mm) 51.4 MP sensor • Hasselblad 43.8 × 32.9 mm 50 MP sensor • Fujifilm GFX 100S has 100MP resolution	• Bulkier, heavier, and much more expensive (tens of thousands of US dollar for an entry version) than full frames • Only for pros
	Action cameras	• Hands-free operation. Small, lightweight, waterproof, and mud resistant. Shockproof • Ample mountability options. Ideal for video. RAW option. Low motion	• No-manual mode • Average still resolution of 12 MP • GoPro Hero 7 Black has a 1 in. sensor
	Instant camera	• Instant availability of a hard copy of an image (instant gratification) • Very affordable cameras	• Low-quality images • Unless digital, not for sharing images • Printed color may fade with time • Photo-paper can be expensive
	High-end smartphone	• Universality (we all have one) • Pocketability • Connectability (easy-to-share images) • Up to three-rear cameras cover from wide angle to zoom (20–40 MP for the mid-range camera)	• Image distortion • Can be as costly as some advanced-compact cameras • Non-interchangeable lenses • Built-in flash blows phone power • No external flash admittance • Only few models have optical zoom

Advantages and disadvantages. Images: Basic Compact: Kodak 10.2 Megapixels (Copyright © 2020 Eastman Kodak Company); Advanced Compact: Nikon 1 V3 (Courtesy of © Nikon Europe B.V., 2019, All rights reserved); Bridge/ SuperZoom. Panasonic Bridge Lumix DMC-FZ2500 (Courtesy of © 2020 Panasonic, All rights reserved); CSC/ Mirrorless: Fujifilm XT3 (Courtesy of © FUJIFILM Corporation, All rights reserved);DSLR: Canon EOS Rebel T7i (Courtesy of © Canon Inc., All rights reserved); Medium Format: Hasselblad X ID-50c (Courtesy of © Hasselblad 2020, All rights reserved); Action cameras: GoPro Hero8 (Courtesy of © 2020 GoPro, Inc., All rights reserved); Instant camera: Leica Sofort (Courtesy of © 2020 Leica Camera AG, All rights reserved); High-end smartphone: Huawei P30Pro (Courtesy of © 2020 Huawei Technologies, All Rights R Co., Ltd., All rights reserved)

11.2.1.1 Basic Compact

Compact digital cameras, also known as point-and-shoot cameras, are very simple to use. The majority of these cameras offer automatic mode, although there are some models in the market with manual or semiautomatic control mode available. Scene selection is one of the few settings allowed. The lens cannot be changed and its image quality is not optimal. It is customary to have an integrated flash in the camera body. The sensor size is small, although the final quality of the image is often software enhanced. Given that the individual components of the camera are of a lesser quality and that lens and some photo parameters cannot be changed, the quality of the image is poor. Basic compacts only take JPEG format.

Due to the constant improvements in smartphone cameras, the compact camera category is receiving a lot of competition; most camera manufacturers are not investing much in keeping the low end of this category alive. Basic point-and-shoot cameras are affordable, light, and easy to use, but in general they do not render the quality required for good medical photography. Basic compacts are "kids" cameras (Fig. 11.1).

11.2.1.2 Advanced Compact

Advanced-compact (or advanced point-and-shoot) cameras, although still far away from CSC/DSLRs, are a step forward in the direction of better-quality images given that they can provide for full manual control of settings and RAW shooting. Some come with low light mode with up to ISO 12800 (Canon PowerShot G12, although the standard for this category is a much lower ISO setting such as ISO 1600), HDR mode, image stabilizer, HD movies, an attached focal-length adjustable telephoto lens, and some limited lens accessories catalog. Best advanced-compact cameras have 1/2.3 in. sensors (5.64 crop factor) with resolutions in the vicinity of 20 MP, although some Canon and Panasonic Lumix models feature a 1-in. sensor (2.7 crop). Optical zoom can vary from 3× to 45×, for focal lengths of equivalent 21–1080 mm (Canon SX 430 IS).

On the other hand, given their small size sensor, compact cameras typically cannot clearly separate foreground from background; they are what is called an "all-in-focus" device. This can be a problem in portrait photos where you want to get rid of the background by blurring it (*bokeh* effect). In medical photography, where sharp images and large depth of field is desired, this type of focusing is not ideal either.

If under budgetary and portability restrictions, advanced-compact cameras can be adequate for medical photography. The classic Canon G12 (10 MP resolution in a 1/1.7 in. or 7.6 × 5.7 mm sensor cropped down to 4.55) is an advanced-compact model that allows the attachment of a dermatoscope and/or an external flash. The most recent released Canon models such as the G1x and G5x have been upgraded with superior resolutions. Nikon provides compact cameras such as

Fig. 11.1 Basic Compact Cameras. On the left, Nikon Coolpix W100 (Courtesy of © Nikon Europe B.V, 2019, All rights reserved). On the right, Fujifilm Finepix WP130 (Courtesy of © FUJIFILM Corporation, All Rights Reserved)

Fig. 11.2 Advanced Compact Cameras. On the left, Canon G12 (Courtesy of © Canon Inc., All rights reserved); on the right, Nikon 1V3 (Courtesy of © Nikon Europe B.V, 2019, All rights reserved)

the Series 1, Nikon 1V3 being the very popular model. All of them have Wi-Fi connectivity (Fig. 11.2).

11.2.1.3 Bridge

Shearing some features with an entry-level CSC/DSLR, bridge cameras were originally defined as a bridge between advanced compact and CSCs/DSLRs. They feature a non-interchangeable zoom lens covering from wide to telephoto focal lengths (typically 25–600 mm full frame equivalent for a high-end bridge). They have smaller-sized sensors compared to interchangeable-lens cameras. Most bridge cameras pack a 1 in. sensor (sized 12.8 × 9.6 mm, crop 2.7) or smaller. With a DSLR-style handling, they feature automatic and manual shooting modes and a full range of creative controls. Today's bridge cameras have evolved in image quality due to better sensor and software technology, even bypassing high-end interchangeable-lens cameras in some aspects. These high-tech small sensors can be quite fast when reading information which allows shooting video speeds of up to 14 frames per second in 4 K or 960 fps in SD mode. An additional advantage of a smaller sensor is the ability to build a fast telephoto lens around it [1].

Bridge cameras are smaller and lighter; when considering lenses costs, they can be more affordable than interchangeable-lens cameras, and their image quality can compete with entry-level DSLR/CSCs carrying small sensors.

A list of good bridge cameras should include Sony Cyber-Shot RX10 IV, Panasonic Lumix FZ2000/2500, Canon PowerShot SX 70 HS, and Nikon Coolpix P1000 (Fig. 11.3).

11.2.1.4 Interchangeable-Lens Cameras (Mirrorless and DSLR)

Given the actual evolvement of interchangeable-lens cameras in favor of compact system cameras (CSCs) and away from DSLRs, and given that both categories share a family of equally sized sensors, we tend to think of CSCs and DSLRs as two expressions of the same basic category, with sensors in the 1.0–2.0 crop factor range.

DSLR cameras inherit the optic design of old times 35 mm film reflex. In DSLRs the photographer can view the scene through the lens in the optical viewfinder (OVF). An array of mirrors and a system for synchronizing shutter opening with a moving mirror allows the photographer to see the scene when not shooting or the sensor to see it when shooting. In a CSC camera, the imaging sensor is always exposed to light, giving the photographer a digital preview of the image either on an electronic viewfinder (EVF) or on a rear LCD screen. A more detailed description of how does a DSLR/CSC camera work can be seen in this book in Chap. 12.

The quality of the digital image produced by the sensor depends on the size of the individual pixels and the amount of pixels in sensor's array. Cameras with bigger sensors can render better-quality pictures. Full-frame sensor (24 × 36 mm as in 35 mm film photography) cameras can render top-quality images, although if photos are not

Fig. 11.3 Bridge cameras. On the top left: Sony Cyber-Shot RX10 IV (Courtesy of © 2020 SONY Europe B.V., All rights reserved); top right, Panasonic Lumix FZ2000/2500 (Courtesy of © 2020 Panasonic, All rights reserved); Bottom left; Canon Power Shot SX 70 HS (Courtesy of © Canon Inc., All rights reserved); bottom right, Nikon Coolpix P1000 (Courtesy of © Nikon Europe B.V, 2019, All rights reserved)

intended for being magnified, fractional (smaller than full-frame) sensor DSLR/CSC cameras can successfully do the job. Fractional-sensor (crop factor bigger than 1) interchangeable-lens cameras can produce high-quality images when reproduced at common size digital displays or printed paper formats.

The main advantages of DSLR/CSC cameras are the interchangeability of lenses and the use of bigger sensors as compared to advanced compact, bridge, or smartphones; these two features add up to better-quality images. All DSLR/CSC cameras allow RAW and JPEG formats. All of them offer manual mode and other pre-programmed camera modes. A wide range of attachments and flash options are available.

Nowadays, a good-quality picture can be achieved either by using a DSLR or CSC with the right sensor size/quality. Historically, for many decades, SLR cameras have been the cameras of choice for professionals, even before the digital versions were born. Today, within professional photographers, CSCs are competing strongly for the market of interchangeable-lens cameras; mirrorless cameras seem to be the wave of the future. Having most of the features of DSLR cameras, mirrorless cameras are smaller and lighter, and the camera-lens system is a little less expensive than with DSLR cameras. One small disadvantage of CSCs could be the need for more spare batteries given that powering a screen continuously takes up a lot of power. Another disadvantage may be a lesser availability of lenses for CSCs as compared to DSLRs, a problem that's been quickly solved by the market.

Rather than subclassifying interchangeable-lens cameras into DLSR or mirrorless, we favor separating them by their potential for better-quality images, i.e., sensor size: full-frame vs. fractional sensor. Other things being equal, maybe the most important factor for quality images is sensor size. A big sensor allows a combination of more/bigger pixels that translates into higher resolution and less noise. As will be explained in Chap. 12, the final use of the image suggests the sensor size best suited for the job, and hence the camera viewer system (either DSLR or mirrorless) becomes less relevant. At the end, it is to the camera user to decide which camera viewer system is more compatible with the user's personal handling taste.

Some of the best full-frame camera models include not only DSLRs such as Nikon D850 and Canon EOS 5D Mark IV (Fig. 11.4) but also Nikon D750 and Nikon D5 and Canon EOS 6D Mark II. There has been an historic debate among Canon and Nikon enthusiasts about who builds the best SLR cameras. The truth is both manufactures build great cameras. Maybe the dilemma can be settled by answering the following question: which currently offered camera model best suits to your personal needs?

In the mirrorless group, Nikon Z6 and Sony A9 are among the best full-frame choices; other candidates are Sony Alfa A7 III, Nikon Z7, Canon EOS RP, Panasonic S1, and Sony A7 III (Fig. 11.5).

Within the interchangeable-lens category, Nikon D7500 and Canon EOS Rebel T7i are two good choices of DSLR with fractional sensors (Fig. 11.6).

Camera brands other than Canon and Nikon that already have a stronghold in the DSLR niche are developing strengths with mirrorless units that today seem to be the way to go in interchangeable-lens cameras. Fujifilm X-T3 and Lumix DC-G9 are two examples of the best mirrorless fractional-sensor cameras; other top player in this group is Canon EOS M6 (Fig. 11.7).

11.2.1.5 Medium-Format Cameras

When magnification of quality is an issue, bigger-than-full-frame sensor cameras (crop factor smaller than 1.0) can be the equipment of choice. Sensor sizes larger than full frame (36 × 24 mm) but smaller than "large" format (4 × 5 in., or 130 × 100 mm) are said to be "medium format." Maybe there are no many occasions in medical

Fig. 11.4 Full-frame DSLR cameras. On the left, Nikon D850 (Courtesy of © Nikon Europe B.V, 2019, All rights reserved); on the right, Canon EOS 5D Mark IV (Courtesy of © Canon Inc., All rights reserved)

Fig. 11.5 Full-frame mirrorless cameras. On the left, Nikon Z7 (Courtesy of © Nikon Europe B.V, 2019, All rights reserved); on the right, Sony Alfa A7 III (Courtesy of © 2020 SONY Europe B.V., All rights reserved)

Fig. 11.6 Fractional sensor DSLR cameras. On the left, Canon EOS Rebel T7i (Courtesy of © Canon Inc., All rights reserved); on the right, Nikon D7500 (Courtesy of © Nikon Europe B.V, 2019, All rights reserved)

Fig. 11.7 Fractional sensor mirrorless cameras. On the left, Lumix DC-G9 (Courtesy of © 2020 Panasonic, All rights reserved); in the center, Canon EOS M6 (Courtesy of © Canon Inc., All rights reserved); on the right, Fujifilm X-T3 (Courtesy of © FUJIFILM Corporation, All Rights Reserved)

Fig. 11.8 Medium Format cameras. On the left, Leica S3 (Courtesy of © 2020 Leica Camera AG All Rights Reserved); in the center, Fujifilm GFX 50S (Courtesy of © FUJIFILM Corporation, All Rights Reserved); on the right, Hasselblad X ID-50c (Courtesy of © Hasselblad 2020, All Rights Reserved)

Fig. 11.9 Action cameras. On the left, Sony RX0 (Courtesy of © 2020 SONY Europe B.V., All rights reserved); in the center, GoPro Hero8 Black (Courtesy of © 2020 GoPro, Inc, All rights reserved); on the right, Yi 4K (Courtesy of © Yi technology, All rights reserved)

photography for using big sensor cameras such as medium format or even larger, but it is good to know the existence of this very important camera category within professional photographers. Being part of the DSLR's family, Leica S3 uses a ProFormat (30 × 45 mm) sensor with a 64 MP resolution. On the other side, great medium-format mirrorless camera options are Fujifilm GFX 50S and GFX 50R that feature a G Format (43.8 × 32.9 mm) sensor with 51.4 MP resolution and Hasselblad X ID-50c with a 43.8 × 32.9 mm 50 MP sensor (Fig. 11.8).

11.2.1.6 Adventure (Action) Cameras

DSLRs and CSCs are delicate pieces of equipment that are not meant for use under rugged conditions; adventure cameras do. Adventure cameras (also named "action" cameras) designed for adventure sports (extreme sports or action sports) involving a high degree of risk are small, lightweight, waterproof, mud (anyone said blood or human fluids?) resistant, wearable, shockproof, and with ample mountability options. Although ideal for video, their average still resolution of 12 MP (best adventure cameras are in the range of 8–16 MP) and hands-free operation makes them a good compromise solution for taking acceptable quality images (or videos) under very adverse conditions. For field hospital situations, forensic medicine and even for recording surgical procedures in operating theaters (ORs), adventure cameras can be a practical solution to capture medical images that could not be equally done using DSLR/CSC cameras. Some action cameras are reported by the specialized press as among the best GoPro Hero 7 Black, Sony RX0, Yi 4K+, and Olfi One Fire Black (Fig. 11.9).

11.2.1.7 Instant Cameras

Although self-developing film was invented in 1923 by Samuel Shlafrock [2], the first commercial instant camera was developed in 1948 by Edwin Land [3]; it was the Land Camera Model 95 by Polaroid Corporation. The instant camera

Fig. 11.10 Instant cameras. On the left, Fujifilm Intax Wide 300 (Courtesy of © FUJIFILM Corporation, All Rights Reserved) in the center, Leica Sofort (Courtesy of © 2020 Leica Camera AG, All Rights Reserved); on the right, Polaroid One Step 2 (Courtesy of © Polaroid EU 2020, All Rights Reserved)

uses a self-developing film to create a chemically develop print shortly after the shooting. Polaroid images are the predecessors of today's smartphone selfies. There are chemical-instant cameras and digital-instant cameras. Not having a digital sensor, chemical-instant cameras are not digital devices. Nevertheless, instant cameras are included here because they might be of use in medical photography. Instead of searching for perfection, instant cameras' search is for instant results.

Chemical-instant cameras were highly used in scientific applications (e.g., forensic medicine) in the 1970s and 1980s. Today, in smartphone times, there might still be a few medical applications that would benefit from instant paper processing of images such as in field hospitals and situations where the availability of an instant hard copy of an image can make the difference. A patient with a skin lesion in the scalp or back might appreciate an instant photo given by the physician. In the case of chemical photo processing, attention should be placed to the quality of the instant (self-developing) photo-paper; given that there are almost no adjustments allowed to the user, the quality of the instant photo-paper should be a concern (look for freshly stored film from a reputed brand). When it comes to digital-instant cameras (such as the Polaroid Snap), there is only one photo-paper option, the proprietary Polaroid Snap paper.

Fujifilm and some other brands have specialized in this category of instant cameras. Fujifilm Instax Wide 300, maybe the more "professional" chemical-instant camera in today's market, is a medium-format-like instant camera that allows adjusting brightness and flash. Other players in this category, populated with for-the-fun-of-family cameras, are Kodak Printomatic, Leica Sofort, and Polaroid OneStep 2. In the last years, Polaroid is a marketing snap, a digital-instant camera with a built-in color printer that uses a Zink™ inkless technology. Snap uses a cartridge of ten 2 × 3 in proprietary photo-paper sheets but also can record 10 MB JPEG images in a microSD (Fig. 11.10).

11.2.1.8 Smartphones

For certain medical applications, smartphone's cameras have become the best alternative because of their availability (you always carry it in your pocket), lightness, easiness to use, and affordability. Although they are the subject of another chapter in this book, here we will touch some of its basic features.

Today's mobiles have cameras that can take very good pictures even under low light conditions. High-end smartphone brands use multiple-rear cameras to cover from superwide angle to telephoto shootings. As a standard, the front (or selfie) camera is only half good as compared to the rear camera group. For medical photography we will be placing our attention on rear cameras only.

Huawei P30 Pro is a great photographic equipment, thanks to its three rear cameras by Leica: a 16 mm ultrawide, f/2.2, 1/2.7 in., 20 MP; a 27 mm wide angle, f/1.6, 1/1.7 in., 40 MP; and finally, a time-of-flight (ToF) 3D 125 mm SRL-equivalent telephoto, 5× optical zoom, f/3.4, 1/4 in., 8 MP.

Fig. 11.11 High-end smartphones. On the left, Huawei P30Pro (Courtesy of © 2020 Huawei Technologies, All Rights R Co., Ltd., All rights reserved); center left, Samsung Galaxy S10+ (Copyright © 1995-2020 SAMSUNG, All rights reserved); center right, Google Pixel 4× (Courtesy of Google ©, All rights reserved); and on the right, Apple iPhone 11 Pro (Courtesy of Apple Copyright © 2020 Apple Inc., All rights reserved)

Samsung S10+ is another high-end smartphone with triple-rear camera: a 12 mm ultra-wide, f/2.2, 1.0 µm, 16 MP; a 26 mm wide angle, f/1.5–2.4, 1/2.55 in., 1.4 µm dual pixel; and a 52 mm telephoto, 2× optical zoom, f/2.4, 1/3.6 in., 1.0 µm, 12 MP.

Google Pixel 3a is a more affordable Android smartphone with a good-quality rear camera: a 28 mm wide angle, f/1.8, 1/2.55 in., 1.4 µm, dual pixel, 12.2 MP.

In the iOS world, the iPhone XS Max has a dual-rear camera: a 26 mm wide angle, f/1.8, 1/2.55 in., 12 MP and a 52 mm telephoto, 2× optical zoom, f/2.4, 1/3.4 in., 1.0 µm, 12 MP (Fig. 11.11).

Smartphones are very simple to use, do not require formal training and can render good-quality images. As they are connected to the Internet, images can be easily sent for consultation (as in teledermatology) or be added to the patient's record. High-end smartphones can even shoot RAW. In the market there are some attachments available for enhancing the capabilities of smartphones [4], such as dermatoscope (brands such as DermLite, Skiar, and Firefly), ultrasound probe (1–18 MHz range: some of the many brands are Butterfly, Healcerion, Mobisante, Philips Lumify, and Viera), blood pressure monitor with ECG (Withings), otoscope (CellScope and TYM), eyepiece for slit lamp [5] (back of the eye photo), real-time Petri dish reader (for micro-organisms identification), microscope, and glucometer (a blood glucose meter attachment for smartphone is being developed). Given their communication capabilities and provided that all legal/privacy issues are well taken care of, smartphones are ideal for telemedicine (e.g., teledermatology and teledermoscopy) consultations.

Among their disadvantages is the fact that many smartphone images seem to be of good quality when viewed on the device's small screen, but as soon as they are displayed in a laptop or monitor screen or printed on a paper, these photos show a sub-standard quality. Smartphones have image sensors which are much smaller than their camera counterparts (crop factor of more than 6); also, pixel size is much smaller in smartphones than in DSLR or CSC cameras (pixel size of 1.0 µm in the smallest smartphone sensor, compared to 8.4 µm average in a full frame). Smaller sensors with smaller pixels do produce lower-quality images, something that becomes evident when shown in bigger formats (digital displays or printed paper).

Smartphone cameras are, no doubt, a very practical solution for certain medical uses. In the future, smartphones could become the photographic device mostly used by medical professionals. However, there will always be a better quality obtained by bigger high-resolution sensors in high-quality camera bodies with high-quality lenses.

11.3 Lenses

Every manufacturer of DSLR/CSC cameras offers a wide array of lenses to choose from. It is very important to choose the right lens for the job. In this chapter section, we intend to guide through the whole lens family so you can pick up the one more appropriate to your personal needs and those of the medical environment you work in.

Lenses can be classified as macro, superwide-angle (fish-eye), wide-angle, standard, prime, zoom, and telephoto lenses. There is not an "official" classification of lenses by their focal-length measurement; that is why an 85-mm prime lens can also be referred to as 85 mm telephoto. In the description of lens types below, we intend to distribute them along the focal-length spectrum.

11.3.1 Macro Lenses

A macro lens has the ability to focus close enough to achieve a sensor image that is the same size or bigger than the real subject. They are defined by their magnification ratio that ranges from 1× to 10× (magnifications of more than 10× and into the 100× range can be obtained with the aid of a microscope). Using a 1:1 macro lens, the image reproduced in the sensor is of the same size as the subject, whereas using a 1:2 ratio macro lens, the image is up to the half size of the subject; with a 3:1 macro lens, the image can be three times the subject's. If you are using an APS-C with a 1.5× crop factor, the sensor is about the size of halve of an SD memory card (an SD memory card is 24 × 32 mm vs. 23.6 × 15.6 mm for an APS-C non-Canon sensor); an image captured with a 1:1 macro, once displayed or printed in a bigger format, will show more detail than the naked eye can detect. In a way, the macro lens acts as a limited microscope by magnifying images.

Macro lenses are ideal for close-ups (close-up is not a scientific definition; it means any image that shows the subject closer and in more detail than what we are used to see in normal life) in medical photography. Macro photography will show details like hair, scales, and droplets. They come in a variety of focal lengths ranging 50–200 mm. The ideal focal length has to do with the shooting distance: being too close can make proper lighting difficult; being too far can produce more camera movement due to the longer and heavier lens. The need for lighting can induce the choice of a certain macro focal length. A 40–60-mm macro lens could be a good choice for shooting handheld at natural light-illuminated subjects. A 100–200-mm tripod-held macro will allow using larger lighting equipment without obstructing field of view.

There are non-true macro solutions that can help with close-up situations but at the expense of image quality (two or more EV stops at high magnification). Close-up filters attached to the outer ring can magnify +1 to +3 diopters. Extension tubes placed in between the lens and the camera body can also magnify the image received by the sensor (by moving away the lens from the sensor plane, the image formed in it would be of a bigger size).

Macro lenses are a good choice for dermatological photography, where magnification (the size of the subject in the photograph is greater than the life size) of details is desired.

11.3.1.1 Superwide-Angle Lenses (Fish-Eye)

Superwide-angle lenses range from 8 to 24 mm, a very short focal length. They increment the angle of vision of the subject and the perspective and are mostly used in landscape photography, large areas, and small spaces where it is needed to incorporate as much vision as possible. As they distort the reality, they are used mainly for creative photography or photography in confined spaces where distortion is not an issue; they are not used in medical photography. Traditionally, the photographs obtained by using superwide-angle lenses were circular not rectangular. Today, depending upon sensor size, wide-angle photographs can be either circular or rectangular (Canon EF 8–15 mm f/4 L Fisheye USM). For full-frame cameras, the 8-mm "fish-eye" has a field of view angle of 180°. Other common superwide-angle lenses are 15 mm for 110° diagonal field of view, 20 mm for 95° diagonal field of view, and 24 mm for 84° diagonal field of view.

A fish-eye is an ultrawide lens that has an angle of view in the 180° range. Its convex external element captures light from all 180°. A fish eye adds barrel distortion to the image (parallel lines in real life become bended as parenthesis in the photo). There are two types of fish-eye lenses: circular fish-eyes and full-frame (or diagonal) fish-eyes. Circular fish-eyes produce a circular image within a black background, whereas full-frame fish-eyes produce a cropped rectangular image which is the size of the sensor. In the circular fish-eye, the angle of view (e.g., 180°) is always the same in all directions; in a full-frame fish-eye, the angle of view (in this case 180°) refers to the diagonal of the rectangular image (in the 180° full-frame fish-eye, the angle of view will be 100° vertical and 150° horizontal) (Fig. 11.12) [6]. Typical focal lengths for circular fish-eye are 8 mm and 10 mm; 16 mm for full frame. It is a type of lens used for imaging operating theaters or hospital halls.

11.3.1.2 Wide-Angle Lenses

Wide-angle lenses range from 24 to 35 mm. All wide lenses, including of course superwide, take in more of the scene than what is perceived by the human eye. Images appear distorted. Parallel lines appear as if converging. They are used for architecture (20 mm, 24 mm, and 28 mm are commonly used for landscape photography), for shooting at big groups in small spaces (hospitals, working areas, congress rooms, weddings) and in sports (stadiums and play fields); they are not normally used to photograph patients. Common wide-angle lenses are 28 and 35 mm full frame equivalent for repetitively 75° and 63° diagonal field of view.

11.3.1.3 Standard (Normal) Lenses

The standard (also called normal) lenses have a focal length that is approximately equal to the diagonal of the image sensor. With a normal lens, the scene is viewed with a similar perspective to that of the naked human eye, approximately a 55° diagonal field of view. The normal 50 mm lens (also known as nifty-fifty) used on a full frame has a 47° diagonal field of view. A normal

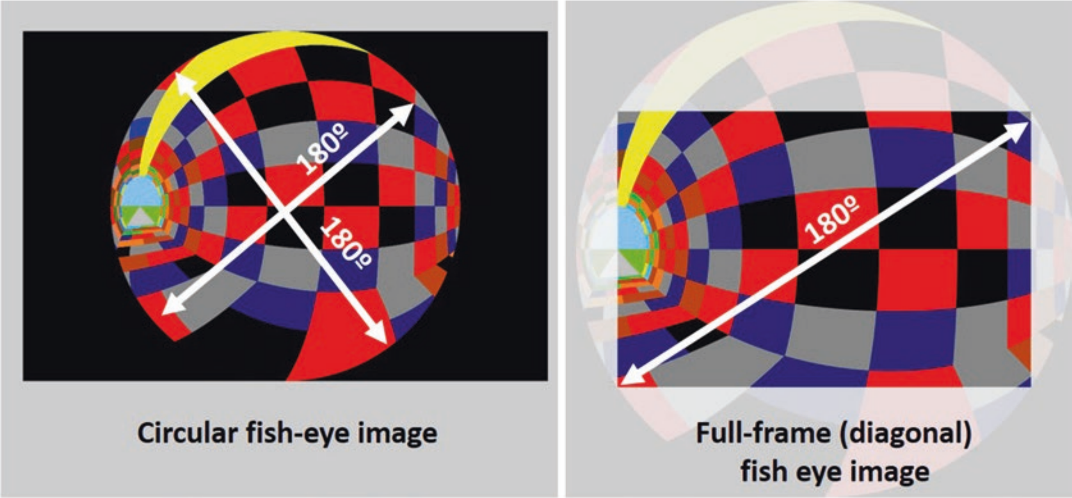

Fig. 11.12 Circular and full-frame fish-eye images (images from https://commons.wikimedia.org/wiki/File:3-2-circular.png, Peter.wieden/CC BY-SA (https://creativecommons.org/licenses/by-sa/3.0) (Left) and Peter.wieden—Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=24242152 (right))

lens can be very much attractive to use in medical photography because of its capacity to reproduce the perspective of the human eye.

11.3.1.4 Prime Lenses

A prime lens can be understood as (a) a lens that is not a variable-focal-length lens (only has one fixed focal length) or (b) a primary (shorted as "prime") lens in a camera lens system. Prime lenses characterize themselves also by their wider diaphragm opening (typical in the f/2.8–f/1.2 range) and their higher optical quality arising from the simplicity of not being a zoom with additional glass inside. Prime lenses are significantly sharper than zoom lenses. Common focal lengths for primes are 35 mm, 50 mm, 85 mm, and 135 mm, although there are in the market other primes with different focal lengths.

Prime lenses are more luminous, hence more adequate for portrait photography, where detail is important. The 85-mm prime is widely used for environmental portraits where emphasis should be on face details and not on the environment; you get a much blurrier bokeh effect with an 85-mm than with a normal 50-mm lens. Another advantage of the 85 mm above the 50 mm is that you need not to be that close to the subject, allowing for better lighting of the subject (it's easier to play around with flash units and other lighting gadgets and not get undesirable shadows when farther away from the subject).

We highly recommend primes above zooms for medical portrait photography. Zooms has the convenience of changing rapidly the focal length but at the expense of image quality. In a clinical environment, where the camera can be permanently placed in a tripod and the lighting setup remains unchanged, a prime will get more light for the same aperture (may be +2EV) with the consequence that you can lower the ISO setting. Primes will have much less distortion than zoom. A prime is normally smaller, lighter, and less expensive than a zoom.

11.3.1.5 Variable-Focal-Length (Zoom) Lenses

A zoom is a lens that, thanks to its construction with moving parts, allows the focal length to be adjusted. Zoom lenses can maintain focus while changing focal length (a condition called parfocal); if a variable-focal-length lens loses its focus during zooming, it's more properly called a varifocal. In reality, most commercial variable-focal-length lenses sold as zooms are not real zooms; they are varifocal. Here, we assume market's tacit convention and stick to the zoom denomination regardless of focus stability throughout the range. Some compromise in image quality has to be assumed when using zooms. Zooms are very practical to use but at the expense of loss of image resolution at their maximum aperture, especially at the extremes of their focal-length range. This effect is evident in the corners of the image, when displayed in a large format or high resolution [7]. The greater the focal-length range of the zoom, the more exaggerated this effect becomes.

Commonly, zooms deal with focal lengths in the 55–200 mm range. They can be used in portrait medical photography, but keep in mind that prime lens will have a much better performance than zooms in terms of image quality (see discussion above on Sect. 11.3.1.4).

11.3.1.6 Short Telephoto Lenses

Ranging from 67 to 135 mm, short telephotos are compact and lightweight and can be handheld for fast shooting. These are ideal lenses for shooting portraits and candid shots, where the photographer does not want to intrude too much. Those in the lower range in this category could be considered for portrait medical photography (see discussion above in Sect. 11.3.1.4). A telephoto lens is useful when photographing surgical procedures and the photographer needs to stand at a distance.

11.3.1.7 Medium Telephoto Lenses

Ranging from 135 mm to less than 300 mm, medium telephoto lenses are popular with sports and action photographers who can get quite close to the action. For this type of photography, aperture is critical in minimizing blur, particularly when photographing fast-moving subjects. Here, the use of a tripod is recommended. The normal 105 mm lens has a 23° field of view angle; the 300 mm a view angle of 8°. Medium telephotos are not normally used in medical photography.

11.3.1.8 Super-Telephoto Lenses

Telephoto lenses of 300 mm and more (super-telephoto lenses) are the best choice for photographing wildlife and nature and for sports where the photographer cannot get close to the players. The longest focal-length lenses have telescopic magnification, making them a good choice for astronomic photography. Super-telephotos are not only expensive; they are long and heavy lenses that must be used on a tripod. Super-telephotos are not used in medical photography.

11.3.2 Accessories

You should choose a camera body and lens considering your professional needs and those of your medical center; but, before choosing a model, you should also take into consideration the accessories available for each alternative camera. You should check not only the standard accessories in the market but also specialized medical accessories such as dermatoscopes, attachments for microscope, for electrocardiograph or ultrasound units.

11.3.3 Tripods

A tripod is a camera support to help avoid blurred shots caused by camera shake. They can be used to maintain the camera in a prefixed height and be readily available. They tend to be light, not expensive. Depending on what type of medical photography you do, you should include a tripod as part of your setup, particularly when doing portraits. Get a good quality, sturdy and solid to warranty stability and safety of your camera. Manfrotto and Gitzo are well known high quality brands but there are many others. Get expert advise from your local retailer specialized store.

11.3.4 Flash

Flashes can be built-in, pop up, connected on top of a hot-shoe, ring flash, twin flashes, or external flash units.

For macro photography, a ring flash provides an almost shadowless lighting. It is attached to the external rim of the lens. It eliminates the problem of imaging your own shadow or the camera's when taking a close-up picture. It lights anything that your lens can focus on (Fig. 11.13) [8].

Fig. 11.13 Bolt VM-160 LED Macro Ring Light (Courtesy of © 2020 Gradus Group LLC, All Rights Reserved)

Canfield has an integrated ranging lights system that assures repeatable positioning. Exact camera-to-subject distance is assured when the dual-light beams intersect to a single point. It is ideal for facial photography. For photographing close-up, an attachable close-up scale adds a reference of the magnification as well as setting a fix camera-subject distance. This camera includes a cross-polarize filter kit attached in front of the lens that can be raised when not needed (Fig. 11.14) [9].

11.3.5 Diffusers

In the market there are available different types of diffusers for using on hot-shoe flashes. They reduce the intensity of the flashlight received by the subject and soften it (Fig. 11.15). Compact soft boxes or dome diffusers can be used anytime the light source is too close to the subject.

For certain camera models with built-in flash, another solution can be an attachable ring flash diffuser [10] that spreads the light around the lens in a ring shape (Fig. 11.16).

Twin flash systems can be more precise than ring flashes because in the former each light can be adjusted separately (Fig. 11.17) [11].

Fig. 11.14 Canfield TwinFlash RL Clinical Camera with ranging lights system (Courtesy of Canfield Inc., All Rights Reserved)

Fig. 11.15 Phottix Mini Softbox for Hot Shoe Flashes (Courtesy of © 2020 Phottix. All Rights Reserved)

Fig. 11.16 Ring flash diffuser for Olympus camera (Courtesy of © 2017 Olympus Corporation, All Rights Reserved)

11.4 Backdrops

Unicolor backdrops are useful to help concentrate on the main subject and avoid distractions with the environment. Cloth or paper backdrops and their retractable supports can be commonly found in specialized photography stores.One of the best colors is light medium cyan blue PMS 543 (Pantone Matching System). One of its advantages is that it is ideal for all skin colors. Black backdrops reduce shadows, gives a very dramatic contrast, images can be nicely adapted in powerpoint presentations using the black background slide but are only good for light skin types. In general, backdrops come in different colors and can be easily installed and then

Fig. 11.17 Bolt TTL Macro Ring Flash with Transceiver Set (Courtesy of © 2020 Gradus Group LLC, All Rights Reserved)

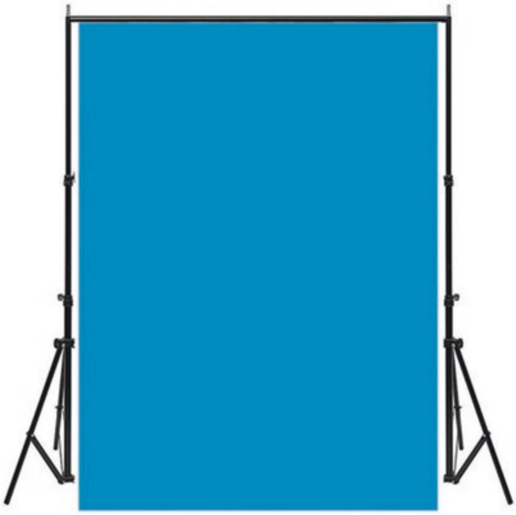

Fig. 11.18 Backdrop and stand. Available on most specialized stores and sites

removed in small spaces (Fig. 11.18). One of the authors, PP, uses an L-shaped wheeled stand which allows her to move the backdrop easily behind wheelchaired patients. This make it convenient for portraits in patients with reduced mobility.

11.5 Placing Mats

Placing mats or octagons (Fig. 11.19) can be of help for standardizing positioning of standing patients. They are ideal for photographs at a 45° angle from one another (frontal, oblique, lateral). You can also build a wood octagon and have the patient "hold" the piece with the feet to mantain the correct position.

The IntelliStage™ by Canfield (Fig. 11.20) can capture 360° photos by using an automated turntable. The table can be flash-responsive or remotely controlled.

11.6 Batteries

Never get without power! Ever! For each camera you need to have two or three charged batteries available at all times. You do not want to find yourself powerless in the middle of a photographic session. Make sure you have the right batteries for your camera and equipment. Avoid cheap brands. You will be always right with your own brand's batteries. Keep batteries in a fresh and not humid place. Also, back up your battery charger; they can also fail.

11.7 Memory Cards

Become familiar with the format of your camera's memory cards. Even though SD format is the most popular, there are other formats too (microSD, CompactFlash, XQD, and CFast). Memory cards can also vary in speed, capacity, and quality. Look for a good brand of fast and good-capacity cards. SanDisk, Lexar, and Transcend have high-quality memory cards of up to 512 GB ranging 95–300 MB/S speed. Keep enough empty memory cards available. They are a very small investment that can save you a lot of time and trouble.

11.8 Other Accessories

Each specialty has its own required accessories and the following chapters will deal with them. For instance, dentists use intra oral accessories

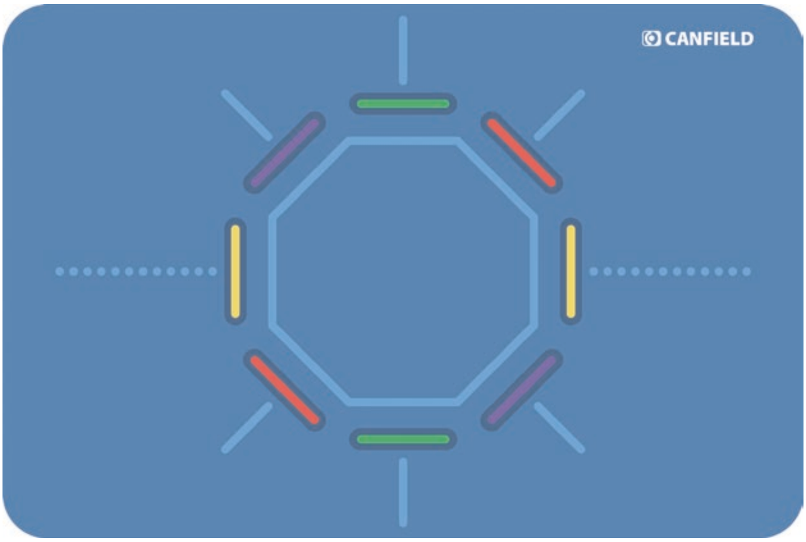

Fig. 11.19 Octagonal positioning mat by Canfield® (Courtesy of Canfield Inc., All rights reserved)

Fig. 11.20 IntelliStage® automated turntable (Courtesy of Canfield Inc., All Rights Reserved)

like stainless steel contrastors, mirrors, check retractors, grey/black/white cards to enhance vision of teeth, specially of back teeth. Pathologists/biologists require special attachments for photographing from the microscope. For most non invasive imaging techniques, manufactures are already incorporating cameras.

11.9 3D Cameras

3D cameras have been around for some years and have been used mostly by plastic surgeons and dermatologists. The system takes multiple images which are then stitched together to recreate a virtual 3D model. 2D projections of the virtual model can be viewed on screen or even printed on paper. Companies like 3dMD [12], Canfield [13], or LifeViz [14] have cameras and software specialized in different types of analysis (Fig. 11.21).

Depending on the equipment and software used, the health professional is allowed to analyze wrinkles, pores, volume differences, depth, pigmentation (redness), and contours, all by automated measurements. 3D images can be used also to better communicate surgical plans, helping the patient anticipate the expected results from an aesthetic surgical procedure. 3D photography can offer many useful features. Grey Mode can reveal contours without color distraction, presenting opportunities for corrective procedures (Fig. 11.22).

Total-body photography (or whole-body imaging, will be covered deeply in Chap. 17) requires photographing most of the skin surface for monitoring patients at high risk of melanoma. MoleMax, FotoFinder, Canfield, and AccuView [15] are some of the different available brands of equipment and software.

FotoFinder Bodystudio ATBM (Fig. 11.23a, b) combines high-resolution total-body photography and video dermoscopy. By using artificial intelligence, moles can be analyzed and provided scores for pigmented lesions.

Canfield has recently put out in the market a 3D TBP system (Vectra WB 360) that reduces substantially the time of image capturing and provides a 3D model that eliminates overlapping

Fig. 11.21 3D cameras. On the left, L3D LifeViz® Infinity (Courtesy of © QuantifiCare, All Right Reserved); on the right, VECTRA H2 (Courtesy of Canfield Inc., All Rights Reserved)

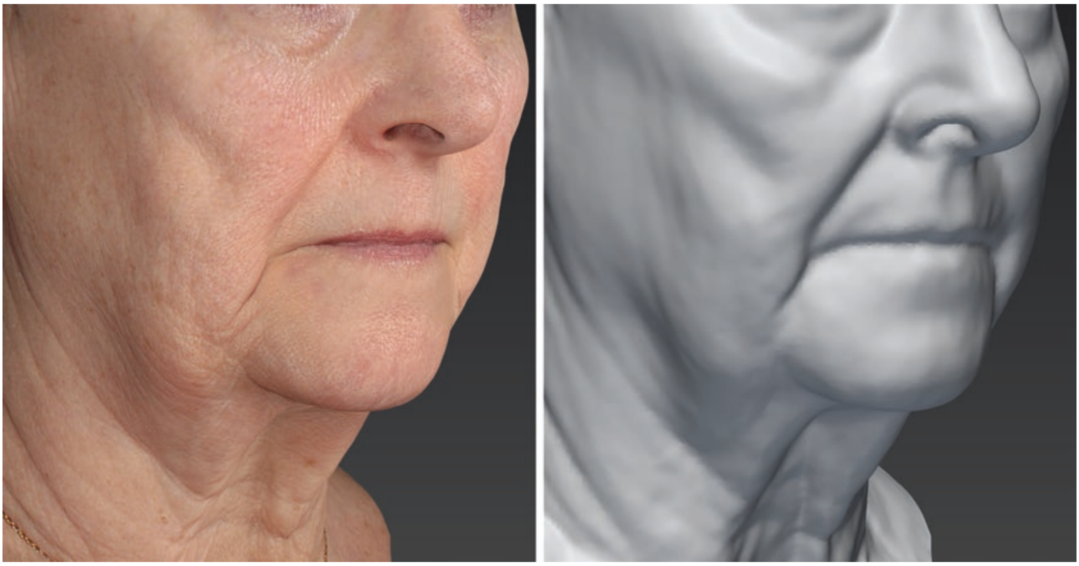

Fig. 11.22 Color Mode vs. Gray Mode in 3D photo. Courtesy of Canfield Inc., All Rights Reserved

of images. The system captures nearly the entire body's skin surface in macro-quality resolution with a single capture (Fig. 11.24).

With the advent and development of 3D printing, some medical applications may arise to create 3D models of a patient's body section.

Barco Demetra® is a non-invasive skin imaging platform which acquires multispectral and white light dermoscopic images as well as clinical photographs of the skin. The images, taken by the DemetraScope, are stored in a protected cloud environment and can be retrieved, displayed, and reviewed both on the device and in a secure web application. It also provides various workflow tools such as lesion localization, evolution tracking, and reporting as well as advanced analytics (Fig. 11.25).

Fig. 11.23 (**a**) FotoFinder Bodystudio ATBM and (**b**) FotoFinder Portrait Stand which rotates 180° from left to right and features nine viewing angles. The chin rest can be removed for lower chin, neck, décolleté or head and scalp photos (Courtesy of Copyright © 2019 FotoFinder Systems GmbH)

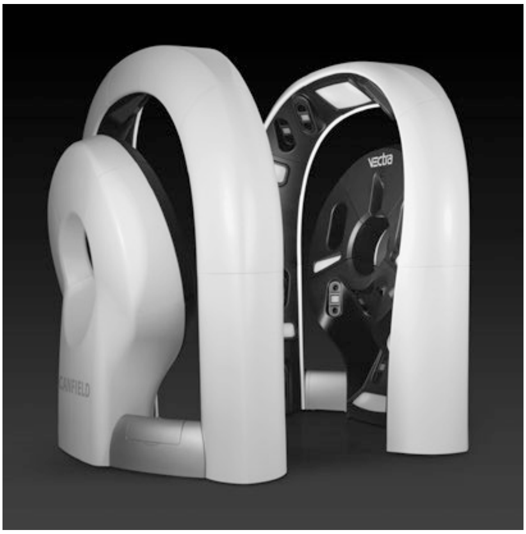

Fig. 11.24 Vectra WB360 whole body 3D imaging system (Courtesy of Canfield Inc., All Rights Reserved)

11.10 Ghosting Photography

When comparing "before-and-after" images, it is important that the two images match (e.g., the position of the irises and the tip of the nose) so to highlight only the differences arising from the medical intervention, not those arising from changes in perspective.

Canfield's MatchPose® image overlay makes it easy to capture "before-and-after" images. It superimposes a translucent live preview over the original image to ensure correct aligning of before-and-after images (Fig. 11.26) [16]. MySkinSelfie [17], an application for monitoring skin conditions, uses a similar approach as well as Imagine® from Leo Innovation Lab [18].

Fig. 11.25 Barco Demetra hand held device with two integrated cameras for clinical and dermoscopic images (Courtesy of Barco NV, All Rights Reserved)

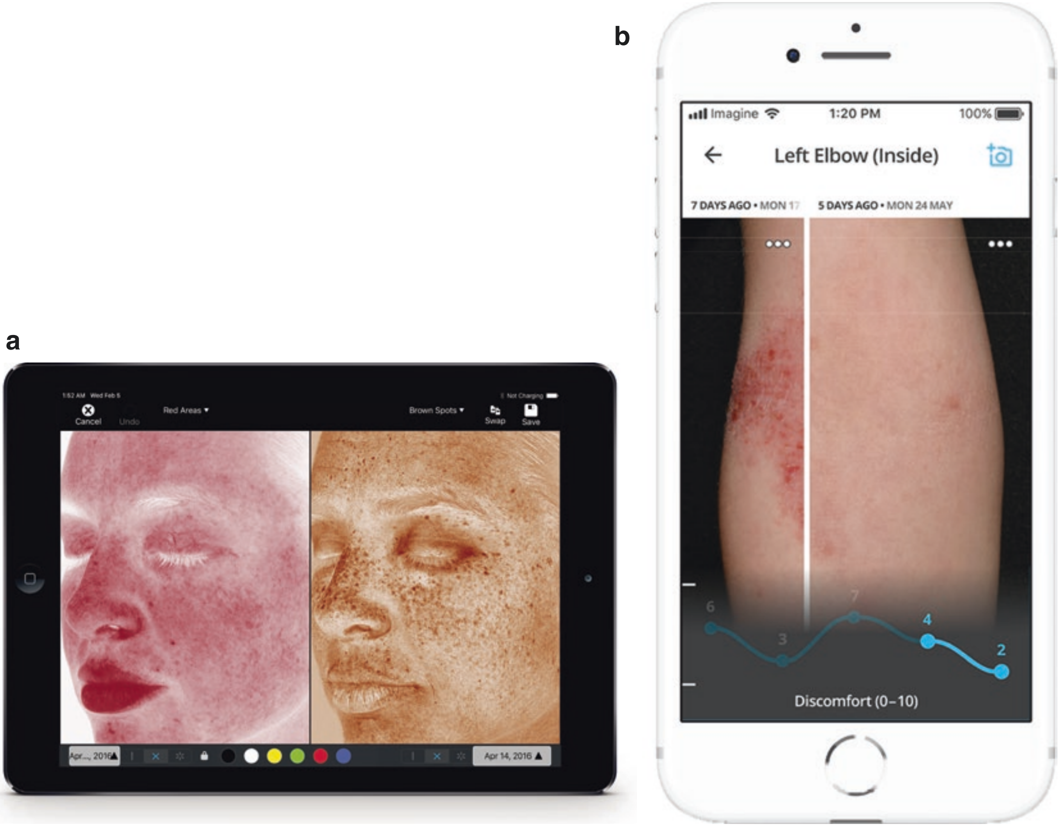

Fig. 11.26 (**a**) (Left side) Canfield's MatchPose® side-by-side comparison feature and (**b**) (right side) Imagine app for monitoring skin conditions (Courtesy of Canfield Inc., All rights reserved)

11.11 Conclusions

This chapter covers some of the most common equipment that might be needed in medical photography, with special emphasis in dermatology, aesthetic, plastic surgery, and dentistry. More specific material will be covered in specific chapters dedicated to other specialties.

Some final comments might deserve mention: keep your equipment in a locked safe place, far away from heat, sun, humid places, vapors, and any liquid sources (do not place your camera next to your freshly brewed coffee!); have them insured against loss or damage; keep your camera and lenses in the appropriate cases; clean the lens only with recommended cloth; avoid uncontrolled multiple users; and keep your hands clean or even wear gloves when grasping the camera, as hospitals can become contaminated. This is specially true nowadays, with COVID-19 pandemia. You need to protect yourself and your equipment from getting contaminated. Desinfect your camera/mobile only with recommended products.

As you get more involved in photography you will find the need to get a more formal training. Take photography courses; do a lot of nonmedical photography to familiarize yourself with cameras and accessories; and get to know your local camera vendor: they are usually highly knowledgeable in their field and will help you solve most daily photographic inconveniences. Finally, have your equipment maintained and fixed only by authorized professionals.

Conflict of Interest The authors of this chapter have no conflict of interest with any of the abovementioned companies. They have tried to cover a very large spectrum of available equipment knowing that the offer is large and probably excellent options have been left out. Some readers might find that smaller and still high-quality brands were not mentioned, and the authors apologize for this. Some of our recommendations will be updated soon as the market moves very fast. All suggestions are based on personal and market information of photographic cameras and their use in medical photography.

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12

Smartphones in Medical Photography

Azael Freites-Martinez, Rainer Hofmann-Wellenhof, and Elena Lucia Eber

Contents

12.1 Introduction

Certain medical specialties are more likely to benefit from clinical photography than others. The visual aspects of many diseases and medical fields such as dermatology, ophthalmology, and plastic surgery lead to an increased use of photography in medicine. Nowadays, nearly everybody uses smartphones daily. A smartphone is a mobile phone that has most functions of a computer and offers the possibility to install different applications or "apps," which are software programs designed to suit a certain purpose of users. Also, the growing worldwide Internet access makes the smartphone and the option of photography much easier to access to everyone, and more attractive as a social tool to connect with other people, and also to doctors through "clinical consults."

Smartphones lead the connections to any trending social media, and this provides endless opportunities to present our best—often digitally enhanced and contrived—self to the public. Applications such as Snapchat and Instagram have built-in filters and picture-editing features that allow users to change their real "natural" phenotype before sharing self-images ("selfies") throughout social media. However, these photo-editing applications significantly affect how people see their self, to the point that the field of cosmetic surgery has actually changed with patients requesting plastic surgeons about surgeries to improve their appearance in selfies [1]. Several studies have examined the psychosocial

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impact of selfies. One study showed found that teenaged girls who regularly posted selfies on social media had higher body dissatisfaction and significant overvaluation of body shape. Frequent selfie viewing behavior was also correlated with lower self-esteem and decreased life satisfaction, which may lead to body dysmorphic disorder, a psychiatric condition characterized by excessive preoccupation with nonexistent or minimal defects in one's appearance [2]. These findings highlight the adverse effects of pictures in social media on self-esteem and emphasize the need to better assess how social media and smartphone use influences attitudes toward cosmetic surgery [1].

Smartphones are evolving medicine. As a positive example, in dermatology, dermoscopic images obtained with a magnifying lens (Fig. 12.1) using smartphones in association with built-in artificial intelligence will most likely prove the most accessible method for future skin lesion analysis, allowing the differentiation between benign or malignant skin lesions even from home [3–6]. Furthermore, in ophthalmology, smartphone-based retinal imaging has

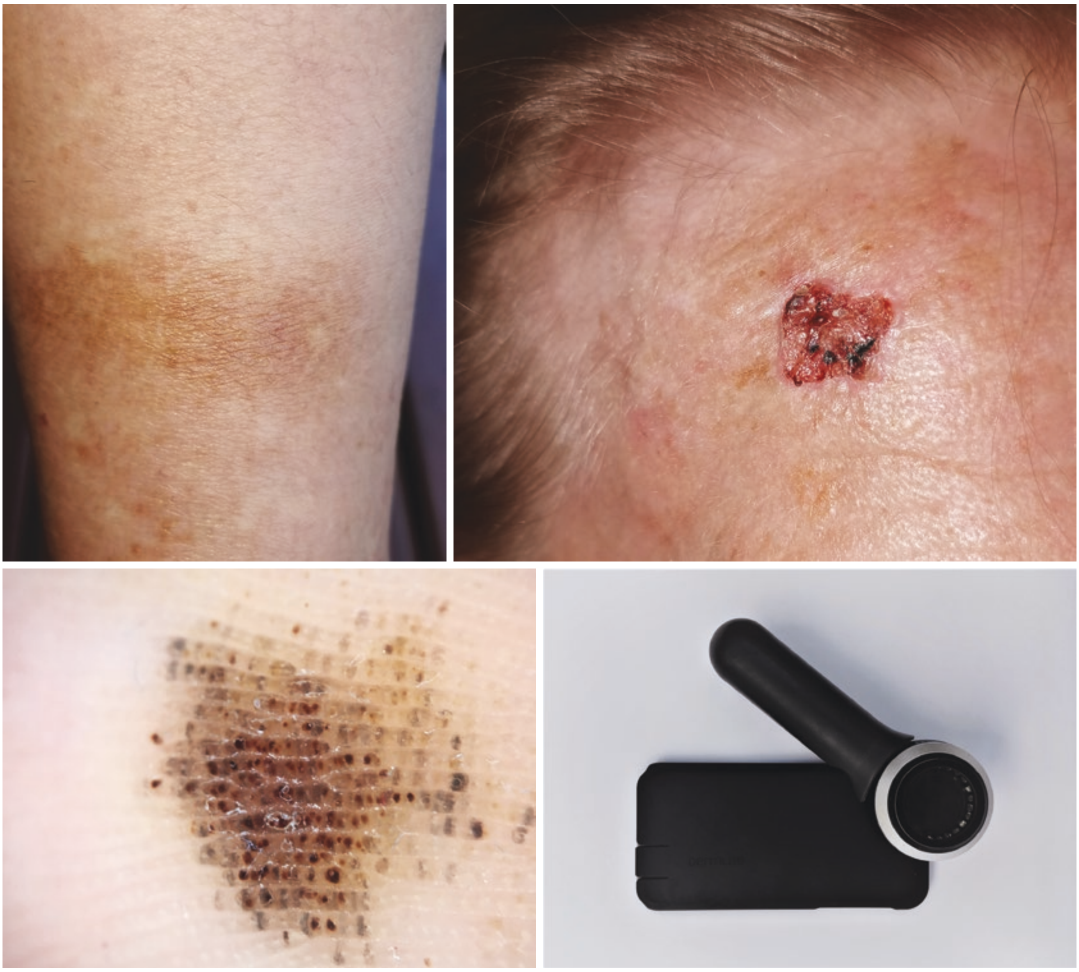


Fig. 12.1 Clinical images of an area of hyperpigmentation on the leg (top left) and of an ulcer on the frontal area (top right), both images taken with a Huawei 30 Pro Smartphone. Dermoscopic image of a melanocitic nevus (bottom left), taken with an iPhone 6S and a dermoscope adaptador by DermLite (bottom right)

emerged as one of the recent cost-effective ways of screening for retinopathy in diabetic patients, and also artificial intelligence-based grading algorithm in combination with validated smartphone-based imaging of the retina of diabetic patients can be used to reliably and accurately screen patients for sight-threatening diabetic retinopathy who could then be referred to the retina specialist for further evaluation and treatment [7–10]. These technological advances will serve as enablers for the medical community. Importantly, technology is not considering a replacement for the medical specialty but, rather, another tool to allow doctors to best care for their patients.

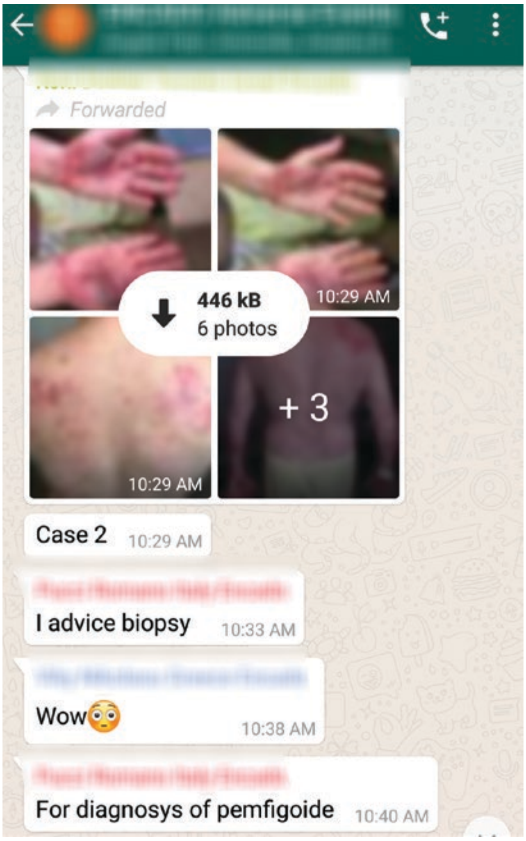
In addition to the described above, the effectiveness of smartphones applications to promote a variety of health behaviors targeting exercise performance, weight loss, diet, smoking cessation, alcohol consumption, and sun protection has been examined in the published literature. Skin cancer prevention is particularly amenable to intervention from smartphone applications by helping individuals monitor UV exposure and provide tailored recommendations and reminders for protecting their skin [11, 12].

This chapter gives an overview about advantages and disadvantages of the use of smartphones in medical photography and provides information about the current use in the clinical setting and legal aspects of using smartphones in medical photography.

12.2 Use on Daily Basis

Smartphone photography is used to seek advice from other experts, to monitor patient's progress and store and document images for education or research in a user-friendly and intuitive way. Several studies show that smartphones (and other handheld devices such as tablets) are good in obtaining quality images and also for quick reviewing and transferring quality images to others worldwide [5]. Smartphone use for clinical purposes is common among doctors, and consultations take place on a regular basis. More than 50% of dermatologists who participated in a questionnaire-based research responded that they are sending and receiving images on their smartphone at least weekly (from colleagues or even patients). It is also notable that young doctors, including the new "technologic generations" (millennials, shaped by a profound expansion of information technology, enhanced social networking, and a connected global culture) [13], tend to take more images with their phones than senior doctors [14].

Smartphone photography can be used easily to get second opinions from doctors in just few seconds, no matter where they may be located. Online web forums, and private groups using connection apps (e.g., WhatsApp, Telegram), are available to seek opinions and advices from international experts through an open discussion (Fig. 12.2).



Case 2 10:29 AM

I advice biopsy 10:33 AM

Wow😳 10:38 AM

For diagnosys of pemfigoide 10:40 AM

Fig. 12.2 Private medical WhatsApp group for diagnosis in dermatology

12.3 Advantages and Disadvantages

12.3.1 Advantages of Smartphone Use for Medical Photography

Smartphones not only enable capturing pictures but also make transferring images possible in an easy and quick way. Prior to smartphones, it was necessary to take pictures with a camera and then transfer pictures to a computer, usually compressed to a ZIP file to be able to transfer per email or using storage devices. It is therefore considered a time-saving, user-friendly, intuitive, and handy device with also excellent image resolution, which could even transfer pictures quickly to other storage devices.

Photography equipment is considered expensive and usually needs a lot of space, as it is in general heavy and unwieldy. With the use of a smartphone, you can save space and money at the same time.

Images quality of smartphones may have been an issue years ago. Nowadays, modern smartphones enable the users to take high-resolution images, and therefore, the quality is in general good [15]. A variety of apps (most of them for free) and accessories are in the market. It is possible to attach appliances (e.g., external macro lenses) to the smartphone to take, for example, dermatoscopic images in dermatology.

Smartphone software is considered user-friendly for not only the younger generations. It is designed to be functional without much background knowledge and is most of the time self-explaining. There are many apps available which make the use of smartphones in medical photography even more attractive, such as CliniPix (storing and organizing clinical photographs), PicSafe Medi (secure sharing of medical photographs among doctors), and Magnifier app (makes magnifying of images possible easily) [3]. Additionally, there is an increasing interest in the development of automated analysis software using computer machine learning/artificial intelligence/deep neuronal learning for analysis of medical images in patients specially with diabetic retinopathy and pigmented lesions of the skin.

Smartphones can be protected by a password (even with fingerprint recognition); cameras usually have not such as protection systems. However, further encryption systems for clinical images are needed to avoid data violation.

12.3.2 Disadvantages and Limitations of Smartphone Use for Medical Photography

Standardization is a must for the adequate use of medical images, especially for patient's follow-up and for research purposes. Sometimes, the lack of consistent light (smartphone flash, room light), patient position, or the lack of an appropriate and consistent background may limit, for example, an accurate evaluation or grading of a medical condition. A professional camera has better and more specific appliances to get constant image features and the reproducibility of the images [16].

In view of smartphone's camera implements, there are more limitations compared with a professional camera. For example, the zoom function of smartphone's camera often produces a blurred picture. Digital zoom (smartphone camera's zoom) is a method of decreasing the apparent angle of view of an image, which is accomplished by cropping the image, with the same aspect ratio as the original, and usually also interpolating the result back up to the original pixel dimensions. It is accomplished electronically, with no adjustment of the camera's optics, and no optical resolution is gained in the process. When comparing the image quality achieved by digital vs optical zoom, there is a significant difference between both zooms. Additionally, the high resolution of a smartphone camera in terms of megapixels does not equate to that of a professional camera with the same megapixel range. This is because of the smaller sensor size of the smartphone camera [17]. However, usually zoom is not strictly required for an appropriate evaluation; external lenses are available to obtain magnified images with excellent resolution. Images taken by the patient with the front camera (on selfie mode) tend to be more distorted and of lower quality (the frontal lens is usually of lees quality than the rear lens). Image distortion is another issue especially when the image is taken in selfie mode. The closer you are to the face, the more distorted it will be because of the perspective effect. This is called barrel distortion. Most smartphones have a single focal length that gives wide-angle vision: they were originally meant for landscape photography. Face distortion caused by an optical procedure is called anamorphosis.

Macro mode is not a standard feature in all the smartphone cameras, which is a limitation when taking close-up images with no lens attached. Even in smartphone cameras having a dedicated macro mode, the quality does not match up to that of the macro mode of professional cameras [17]. There are many legal aspects of using a smartphone for taking images of patients with only verbal consent, and using apps to send images to doctors or receive photographs from patients. The increasing use of smartphone medical photography has raised many concerns regarding ethical and legal limitations. To address these issues, various medical bodies, governing councils, and consensus groups have issued general guidelines for standardization of patients' information and consent forms [10]. However, clinical photography in general and, specifically, using smartphones for clinical purposes have gained acceptance among patients [10], where a shared decision-making for image acquisition could also be implemented with an expected optimal patient satisfaction. Additionally, in a previous study of patients' satisfaction with smartphones for medical photography, most patients (74%) preferred a doctor to be the person photographing them, instead of medical photographer or nurses [10].

Data sent over the Internet is often not transmitted over a secured network. Because of the easy way to send images which are taken with a smartphone, this often may lead to unprofessional use of patient data.

In melanoma care and diagnosis using images through smartphone apps, there is a great potential cost-benefit to the consumer if melanoma apps aid in early detection and treatment. However, there does not yet exist a proven correlation between the cost of apps and outcomes. Particularly in healthcare systems where care is expensive or difficult to access due to distance or waiting lists, there is a risk that after paying for and receiving reassuring advices from an app, a patient may neglect to seek appropriate medical care [18].

Although the artificial intelligence algorithm could replicate manual grading or diagnosis by medical specialists using images analysis, it would not be able to overcome physical limitations, such as the inability to acquire photographs with smartphones in some patients due to, for example, poor light, or in ophthalmology, mydriasis, or poor image quality due to media opacities like cataracts [8, 19, 20].

12.4 Tips and Rules

There are a few tips and rules for using a smartphone in medical photography:

- Get the written consent of the patient to both take the images and store them; also follow the law of patient safety and local data protection.
- The background should be neutral and of one color; this should be informed to patients and colleagues for appropriate imaging.
- The lightning and position of the patient are very important, as those are the key factors to get a realistic picture.
- Patients' smartphones could be used for follow-up and biopsy site selection; as the patient stores the images on their own smartphone, there is no breach of data protection, and patients seem to prefer this method as opposed to giving others permission to store their sensitive information [4]. However, this may lead to loose images and to difficulties for long-term follow-up.
- Apps such as CliniPix, AppWorx, and PicSafe Medi are very useful for storing and organizing clinical photographs. It is primarily intended for physicians who need to keep track of diseases (such as in dermatology).

However, it might be useful to anyone wanting to securely store photographs in smartphones and keep them organized for clinical use.

- Image color filters might be helpful to better understand or visualize diseases.
- For portrait photography, keeping farther away from the subject will reduce distortion. High-end smartphones are including an algorithm that is capable of correcting the distortion present in smartphone portrait photography. In addition, some have already incorporated optical zooming.

12.5 Legal Aspects

The use of clinical photographs, taken with mobile devices, is changing healthcare for the better, but these images require special storage and consent. Capturing and transferring images by a smartphone using certain apps raise legal issues. The use and transfer of images require the informed consent of patients. Consent can be given implicit or explicit. It may be given in a written form or just verbally. For the purpose of education, research, and social media publication (especially common in aesthetics and plastic surgery), written consent is required. Furthermore, data protection must be ensured. This includes secure systems for data storage as well as a secure apps or system to transfer images [21].

Keeping a smartphone only for medical use left in the office has several advantages:

- The patient perceives the equipment as part of the medical instruments. This will reduce the discomfort of seeing his images taken by the physician's personal phone.
- Photographs can be taken and downloaded later. You will not be taking the patient's image with you outside the hospital premises.
- You will still have the possibility, previous acceptance from the patient, to share these images with the medical record, a colleague for second opinion, or eventually for academic purposes.
- You will have the advantage of taking images inside the hospital using a small pocket size equipment.

For direct to consumer (DtoC) teleconsultations, where the images are sent directly by the patient, it would be advisable that these apps include in their presentation a short and friendly tutorial on how to take good medical images.

12.6 Conclusion

Smartphones should be used in medical photography as a tool in therapy and diagnosis due to their high practicability and efficiency. However, negative experiences with the smartphone use of pictures and "filters" in social media are described, such as higher body dissatisfaction and significant overvaluation of body shape, resulting in psychological distress and changing in medical aesthetics and plastic surgery lineages. Smartphone photography quality is evolving positively in a fast manner, allowing taking better images and prompt remote diagnosis. However, there is a need to make sure that there is always a secure app or system, which protects the privacy of the images both while storing and during transfer. Also, documentation of the informed consent of patients is necessary in terms of liability. Due to the potential risks of liability and privacy issues, further education and common policies are required.

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Setting Up a Photographic Medical Studio

13

Tom Bialoglow and Paola Pasquali

Contents

13.1 Introduction

Most physicians will take pictures of their patients by themselves. Most of these pictures will not be good; others can be very appropriate for the use they were meant for. Setting a photographic studio is a way of giving medical photography the importance it deserves. The studio is more than just a room: it is a concept. It is the physical space where a non-invasive imaging technique will take place. There is no better way to standardize your pre- and post-cosmetic procedure photography than to invest in a medical photo studio. Once the initial investment is done, getting photographs done in a standardized manner will be much simpler.

13.2 Why Do We Need a Photographic Studio?

Creating a photo studio is not a trivial task and requires an investment. For best results, a room should be dedicated to studio photography, and a medical photographer should be engaged for installation and training to ensure photographs are suitable for use in a medical practice engaged in medical photography. For the purpose of this chapter, most considerations will deal with dermatology, plastic surgeons, and orthopedic practices that deal with pictures of the skin lesions, whole face, total body, and extremities.

In general, a good piece of advice is to keep use of the studio simple. The more complex the solution, the more frequent the problems.

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P. Pasquali (ed.), *Photography in Clinical Medicine*, https://doi.org/10.1007/978-3-030-24544-3_13

A photographic studio has several advantages:

- Reduces time required to take a photograph in the correct conditions.
- It gives more privacy to your patient when taking the picture.
- Contributes in professionalizing your medical image (brand).
- A formalized photographic act reassures your patient.

Disadvantages can be:

- It requires an investment.
- It works ideally with a medical photographer or trained personnel.

Each studio will need to be designed according to the needs of the user. Plastic surgeon's requirements will probably be different from a department of dermatology's or a hair specialist's.

Ultimately, you want to create a room that is comfortable for patients and easy for staff to use and produces excellent, consistent results. Let's discuss how to make this happen.

13.3 Standardizing Photographs

When one speaks about a correct medical photograph, the first word that comes into mind is standardization. This means that by following certain rules, all our images will have quality and will be comparable over time.

Setting up a photographic studio requires taking into considerations aspects that regard the patient, the room, the equipment, and the photographer.

13.3.1 Patient Considerations

As mentioned in other parts of this book, the first requirement before photographing a patient is to have her/his consent. An informed consent form needs to be explained as well as the extent of use of the pictures (medical record, sharing with colleagues/teleconsultation, publication, publicity for the clinic).

As this chapter deals with the studio, make sure you have a space/area/table/chair where sitting and discussing these aspects is possible and where the patient will be able to comfortably read and sign the consent.

Once accepted, the person in charge to take the picture (medical photographer, nurse, technician, and physician) needs to explain what is expected from him/her.

Discussing the photo session with the patient is often overlooked. Telling the patient what to expect and what you will need them to do is important in enlisting their aid. Explaining to a patient that you want them to move in fine increments is extremely helpful when you are fine-tuning their poses. Advise a patient not to move after you have taken their photo until you check and approve the photo. This way if you need to take the same photo again or need to refine the pose further, the patient is still in the same position.

Patient's privacy is of extreme importance. Respect for intimacy is crucial. The room needs to be in a comfortable temperature for your patents, especially during winter time. They need a seat in the waiting room or area where they have to wait to be photographed, a proper place for their belongings, and some hooks to hang clothing from. Help to older people or a handicap is essential. If room size permits, a draped changing area is nice to provide for patients. This would need to be behind your studio flashes so as not to block any light. For body photography invest in disposable undergarments. This makes for more consistent and professional pre- and post-procedure photographs than photographing patients in their underwear. In addition, modesty garments will make patients feel more comfortable by avoiding unnecessary exposure and photographs of sensible areas.

Hair ties, hair pins, and hairbands in black and shades of brown should be available for restraining hair. Jewelry should be removed and allowed to be placed in a safe place. Make up has to come out for face photography. Keep disposable fabric soft makeup remover tissues at hand.

Positioning aids are helpful in your quest to standardize studio photos. They help get your patient close to the position they need to be in for photos, but the photographer will often have to fine tune the patient's pose.

A backless stool for the patient to site on during facial photos should be kept in your photo studio. Acquire a small stage (24 × 24 × 10) on which the patient can stand so your photographer may not have to angle the camera downward for capturing photos of the lower legs.

For frontal views, the patient can simply look into the lens. Other views can be placing the patient on a positioning mat marked for foot placement and for frontal, oblique, and lateral poses that can expedite and help standardize patient poses. For oblique and lateral images, providing stickers on the wall for the patient to turn toward and look at will help keep them in place after the photo has been taken and before you turn them to the next pose. Another option is an octagonal piece with the numbers indicating the position. By having this piece of solid material, it will stay more firmly in place, and it will be more resistant; in addition, patients will place their feet tight to the piece further helping them maintain a fixed distance.

The manner in which you ask your patient to pose for the photos and how you ultimately compose your photos for specific anatomy and procedures can benefit from standardization. The author (TB) has collaborated with the American Society of Plastic Surgeons (ASPS), the American Society of Dermatologic Surgery (ASDS), and the American Academy of Facial Plastic and Reconstructive Surgery (AAFPRS) in photographic standard posters. These posters are sold by the respective societies though in some cases to members only. Frame and display the appropriate poster in your photo studio as a ready visual reference for your staff. Review photos with your staff periodically to ensure they are adhering to the standard you have chosen. These photos will also help patients understand the required position they need to take.

13.3.2 Room Considerations

It is ideal to have a special room for medical photography.

Windowless rooms are preferred but windows can easily be covered with blinds or curtains to keep the lighting environment consistent and to ensure patient privacy.

Rooms should be rectangular at least 6′ by 10′. Pick a room where temperature is comfortable and stable. Remember, your patients will sometimes be wearing only a disposable modesty garment. Door should be mounted to swing into the room so that upon first opening the door the patient is hidden. This way if staff mistakenly opens the door during a photo session the patient is not immediately seen, and the photographer can stop staff from opening the door further. Having a flag outside the room indicating a photo session is in progress is advisable. Mounting a sliding curtain at the door lintel is another possible solution.

One of the narrower walls will become the patient backdrop. That wall should have no electrical or data outlets and should be painted a flat light blue. Some may opt to paint the wall black to make patient shadows cast on the backdrop less conspicuous. TB prefers blue as it is more aesthetically appealing and there is good contrast between light blue and dark skin and hair. Some prefer a neutral color wall, remembering that shadows will be more evident against light colors. Side walls should be painted a flat light gray, white, or neutral color so as not to impact the color of the photos. Some hospitals or clinics that have no such physical space available can set one wall for photography (Fig. 13.1).

Besides preparing a wall, other options for backdrop are fixed or mobile stands (commercially available). PP uses for portrait photography of wheel-chaired patients a wheeled stand with a hanged black velvet to position behind after placing a bib.

If you plan on using a mobile stand, the floor should not be carpeted as this can make moving and adjusting the mobile stand difficult. Ceiling should be white acoustic tiling or painted flat white. Non carpet flooring will facilitate cleaning from one patient session to another, a requirement that has become even more relevant during the coronavirus COVID-19 pandemic.

Fig. 13.1 Palette of suggested colors to paint a wall and use it as backdrop

Compared to studio flashes, room lighting is quite dim and typically does not interfere with studio photographs. Your camera will need a bright room to accurately focus. That being said choose ~5000 K LED banks under large diffusers positioned down the midline of a room.

Potent flash light and a patient located away from the wall in a dim light room obviate the need for a backdrop as the flash will illuminate the subject, leaving the back black.

If you will have a computer in your photo studio, add a quad electrical outlet and data drop on the right or left 5 ft from the patient backdrop wall. If you will be using this PC to import and manage your photos, a data drop is essential as Wi-Fi can be slow when handling high-quality, high-resolution digital photos. Remember to turn off the monitor at the end of the photo session so that the patient's images are not visible to anyone.

13.3.3 Equipment Considerations

Maintaining the equipment in the photographic room has many advantages:

- You will always know where the camera is to be found.
- By placing them in the appropriate shelves, they will have less chance for accidental falls caused by mobilizing them.
- Equipment will be adjusted to standardized light and distance.

It is important to guarantee that the room dedicated to photography has safety conditions (safety windows, keys available only to certain personnel). Equipment is expensive and safety is an important issue.

Equipment should include:

- Lighting
- Cameras
- Lenses
- Tripod (tripod, monopod, or mobile camera stand – the capture plane can be kept parallel to the anatomy being captured and distance to the patient can be better managed)
- Positioning mats or numbered octagons
- Hair pins, diadems, make up removal
- Chairs to sit patients

- Backdrops (different colors)
- Stands for backdrops
- Different accessories for cameras: batteries, memory cards, chargers
- Specially designed stands for hair photography

Most of this has been covered in the chapter on Equipment. We will focus mostly on artificial lighting.

In a photo studio, exposure times are short, which helps minimize patient and operator motion in photos. Standardization covers aspects that relate to:

- Light intensity
- Colors (white balance)
- Distances
- Angle of incident light
- Camera parameters
- Focal length

13.3.3.1 Lighting

Outside of choosing the right room, lighting selection might be the most important component in your photo studio. Monolights are the best choice for lighting in a medical photo studio.

Monolights are studio flashes with their own built-in power supply. In short, they plug directly into an electrical outlet; this provides much greater flexibility than other types of studio flashes. Monolights are the best solution for a medical photo studio. They can be used with or without softbox (Fig. 13.2).

Here are suggested requirements for monolights:

- 400 W/S (or greater) power
- Recycling time <2 s at full power
- 5 stops (or greater) power control
- Digital power display
- Audio and visual flash ready indicator
- User replaceable flash tube
- Possesses a sync port
- Cable, optical, and radio sync capability
- Built-in receiver for manufacturer radio sync

Medical photography is a mission-critical application. Entry-level hobbyist monolights are not robust and dependable enough and will likely not meet the requirements above. You will need to invest in professional monolights. Expect to pay USD 600 per monolight at a minimum. It is advisable to purchase a back-up monolight. If one of your main lights stops working, sending it to the manufacturer for repair means being without one of your lights for at least a week. That means no studio photography during that time. Invest too in a spare back-up flashtube.

Fig. 13.2 Examples of studio monolight without a diffused (left); with a diffuser (right)

Along with your monolights, you will need to purchase light modifiers. Softboxes present a narrower profile and better control the spread of light than umbrellas. Softboxes come in many sizes and shapes. Narrow strip boxes are a good choice in a medical photo studio as their narrow profile allows for smaller rooms to be used for photo studios. Choose a strip box 9″–14″ wide and 24″–40″ long.

To attach your softbox to a monolight, you will need an adapter called a speedring (Fig. 13.3). Different brands of softboxes can be mated to different brands of monolights with the right speedring. The speedring will allow you to rotate your softboxes 10–15° with some brands, 360 with others. Generally softboxes are mounted on the light parallel to the walls on which they are affixed so the ability to rotate a great deal is generally not important. The adjacent wall would preclude much rotation anyway.

Lastly, it is best to choose a set of monolights from a manufacturer that has their own radio trigger. An integrated receiver is a simpler solution for triggering your lights than using third-party radio transceivers like PocketWizards. With PocketWizards you would need one mounted on your camera’s hot shoe and one connected to the sync port of one of your monolights. Each PocketWizard needs either batteries or an AC adapter. With an integrated solution, the receiver is built into each light so only the manufacturer’s transmitter is required. A built-in receiver is better too because the monolight will not fire unless it is fully charged.

Fig. 13.3 Speedring adapter for monolight

Installing Your Monolights

Monolights can be placed on light stands, but a more professional and seamless solution is to affix the lights to the side walls. This will create far less clutter and be more aesthetically pleasing. This will create a more consistent lighting environment as light stands are more easily jostled and moved.

To install your lights, you will need the following:

- Two baby plates with a 90° pin
- Eight metal drywall anchors
- Eight finishing washers
- Screw driver or power drill/driver
- Level
- Pencil
- Measuring tape
- Step ladder

Lights need to be equidistant to and aimed at the same angle toward the patient. A 45° angle, if achievable, is ideal. Less than 45° and the lights become too lateral to the patient which can begin to create dense shadows between breasts, between legs, and on either side of the nose. More than 45° is fine but do not exceed 60°.

The following scenario describes installing your lights in a dry-walled environment. Installation of lighting in a poured plaster or stone environment is beyond the scope of this discussion.

First ensure you do not install your light where a door will open against it. If you have no choice, place a door stop in the floor to prevent the door from swinging into your light. Know your local ordinances, it could be that a door not opening all the way can be a code violation.

Next, you will need to examine your wall for metal studs with a stud finder. Locate studs in both walls before installing either light. Always identify where both lights will be affixed to each wall before beginning installation. You could install one light and then find there is a metal stud in the same place on the opposite wall precluding symmetric installation of both monolights.

Mark 68″ (172 cm) lightly on the wall with your pencil—this will be where the bottom of your baby plate will be. Measure the distance from the back wall to where the back edge of the baby plate will be. Ensure the distance from the back wall is the same for both baby plates. Hold the baby plate against the wall, with a level across the top to ensure the top edge of the plate is parallel to the floor. With a pencil lightly mark the four outer holes on the wall.

Before driving your drywall anchors into the wall, use your Phillips head driver to make a small hole where you marked each of the four holes on the wall. Drive the anchors into the wall until it is flush with the surface of the wall. If you measured poorly and find you are hitting a metal stud, sometimes you can use other holes on the baby plate as they will afford additional clearance from the stud. Put a finishing washer around the eight screws that were included with the dry wall anchors. The screw head will recess into the finishing washer to provide a cleaner, more finished appearance than a bare screw head alone. Align a baby plate with the post pointing up with one set of anchors and drive the four screws (wearing their finishing washer) into the wall almost all the way. Place your level across the top of the baby plate and adjust the plate into parallel. Hold the plate in that position as you drive the screws the rest of the way into the wall. Repeat these steps with the other wall.

You can now place your monolights atop the posts and angle both lights into the midline and down about 10°. Bundle any excess power cable—or purchase cables of a shorter length to eliminate excess cable.

If you are designing a room to be used as a medical photo studio with an architect, have your power outlets installed the proximate to where the light will be. This will look more refined than having a long power cable running to an outlet close to the floor. Besides, it reduces risk of accidental tipping over. Have both of these outlets on a switch so staff can easily turn the lights on and off at the beginning and end of the day. The lights will be rather high and the monolight power switch may not be very visible. Having the lights on a switch will keep someone from fumbling around the back of the light and changing settings as they attempt to switch the light off. Some examples of possible settings are shown in Fig. 13.4.

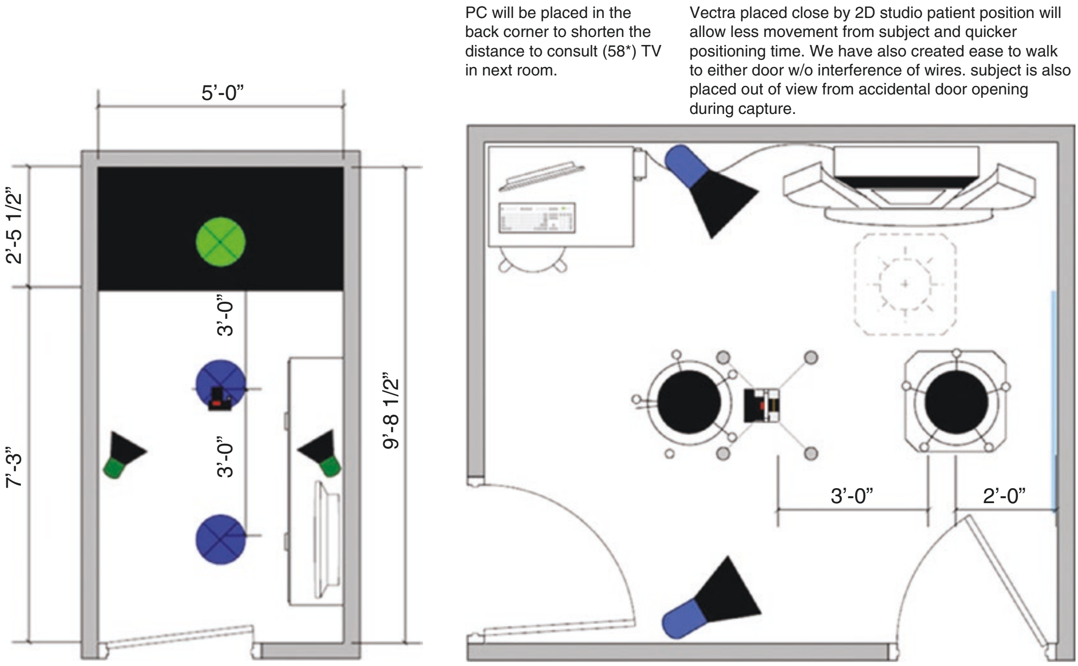
13.3.3.2 Camera and Lens

Any interchangeable-lens camera, mirrorless, or SLR is a good solution in a photo studio. Choose a camera with a viewfinder whether optical or electronic. Do not shoot by looking at an LCD screen on the back of the camera; look through the viewfinder. When shooting in live view with an SLR, there is significantly more lag after depressing the shutter button and some cameras will provide a preview that is too dark to be useful when shooting in Manual exposure mode. Resolution of 16MP or better is recommended. Both full-frame and APS-C cameras will provide excellent image quality in a photo studio as there is an abundance of light.

It is recommended to have a back-up battery for your camera and more than one memory card. Ensure date and time are correct as this information is embedded in the photo's EXIF data and will be displayed in image management applications.

Choose a lens with a fast large aperture of f/4.0 or better. Large aperture lenses are typically better optically and will allow for a brighter image when looking through the viewfinder. The "kit" lenses often included in cameras are rarely the best option for medical photography. Do not use a zoom with a big range. Usually a 3–4× is plenty for clinical photos. 24–70, 28–75 or 24–105 mm zooms will all work well in a photo studio. If you are only taking photos of faces opt for a non-zoom lens, a "prime" lens, this removes focal length as a variable. On an APS-C camera, 60 mm is a good focal length, 105 mm for a full-frame camera.

In a monolight-equipped photo studio, you will have an enormous amount of light for your



PC will be placed in the back corner to shorten the distance to consult (58*) TV in next room.

Vectra placed close by 2D studio patient position will allow less movement from subject and quicker positioning time. We have also created ease to walk to either door w/o interference of wires. subject is also placed out of view from accidental door opening during capture.

Fig. 13.4 Examples of studio setting placing monolights on lateral walls. On the left, the suggested distance from photographer to patient is 3 ft (approx. 1 m) for facial and small field photography; 6 ft (approx. 1.8 m) for half body and total body photography, using a 60 mm lens. It is helpful to mark these distances on the floor for fast reference. On the right, the monitor is placed on the back corner to shorten the distance to consult

clinical photos. This will allow for you to use camera settings to minimize motion blur, keep image noise levels low, keep the depth of focus broad, and maintain consistent color fidelity. In a medical photo studio, it is recommended to use the following parameters and adjust monolight power rather than camera settings to ensure proper exposure:

- Mode: Manual (most common mistake in a photo studio is to use a mode other than M)
- Exposure time: 1/125 S (shorter exposures can preclude proper sync with the shutter)
- ISO: 200 (noise is very low at ISO 200; allows for use of lower monolight power)
- Aperture: f/16 (ensured broader plane of focus)
- White balance: Daylight (studio lights produce light of a daylight color temperature)
- Quality: fine JPG (RAW files optional for those who know how to manage them)
- Size: L (set to the camera’s full resolution)
- Focus mode: AF, Single, all focus points on

Cameras will also have Picture Style, Control, or other modes that dictate how the camera will process the capture to JPG. Set that to Neutral.

A wheeled camera stand, tripod, or monopod can be useful accessories. Marking a spot or line on the floor where your stand will be located helps standardize camera to patient distance (use the zoom to frame anatomy appropriately). Pick a camera platform that allows you to mount a camera in landscape and portrait. Adding an L-Bracket or lens-mount ring to your camera will expedite switching between orientations.

If you choose a tripod, pick a sturdy model with ball-head or pistol grip ball head which allows for quick, intuitive adjustments. Some rolling stands will include LEDs to standardize camera to subject distance without the need to mark your floor.

13.3.4 Considerations on the Photographer

Setting a room with the ideal conditions and purchasing the proper equipment will be meaningless if we do not count the person with the expertise. The ideal situation is to have a professional photographer; however, this is not always possible, mostly for economical or availability reasons. What is possible, however, is to try to have always the same person in charge of photographing. The advantages are that this person will gain expertise over time and know what type of images you need; a second and important benefit will be that patients will feel comfortable if they are photographed by the same individual and understand what is expected from them. A professional relation gets established between the patient and the photographer which facilitates the work of the latter while leaving a sense of ease on the photographed subject.

The photographer needs to know why that picture needs to be taken, what is it that wants to be documented. Since she/he will relate to patients who will sometimes need to undress or show sensitive body areas, proper codes of conduct and dressing are required.

13.4 Image Management Applications

Since you are taking high-quality photos, having an application to manage your photos is a logical final destination for your images. If you have an EMR that could be the final repository for your patient photos, they will treat photos like any other file you might want in the patient record (metadata will be included, DICOM standards).

There needs to be a physical place for storing and post-processing these images. As it is a work that takes time and requires privacy, the same photographic studio could be the place. Pictures can be taken, uploaded, and post-processed all in the same physical area. Proper settings will be required (table, chair, computers, hard disks, software).

There are certain features to look for in an image management application:

- Tethered capture—capture over USB directly into the patient album.
- Ability to add keywords to images—searching by diagnosis, procedure, and/or other criteria makes your photos a much more accessible and powerful resource.
- Show images side by side–essential for pre-/post-procedure review.
- Export images at lower resolution for web use.
- Networkable—if you will want to view your photos in another room other than your photo room.
- Secure—only credentialed users will have rights to data. Data should be sent only through secured systems.

High-resolution, high image quality photos are big files. Calculate 7 MB and greater per photo and you will be taking five or more photos for many of your patients. Wi-Fi is slow for this work. You will want a 1GB cabled Ethernet connection to upload and download images to your server in a networked workflow.

13.5 Conclusion

An ideal medical photograph is the one taken by a person with experience in medical photography who has the proper equipment in a proper physical place. Setting up a studio requires an initial investment that will result in an improvement in the quality of photographic images as well as in the personal (brand) image of the medical center.

Part V

Standardization in Medical Specialties

Standardization in Photographic Documentation

14

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14.1 Introduction

High-quality images are essential for diagnosing, monitoring, consultation, education, surgical planning, medicolegal documentation, and forensic evidence [1]. Comparable images are the fundamental requirement of any clinical documentation, especially in pre and postsurgical follow-up or monitoring. Images will be comparable as long as a standardized protocol of documentation is followed every time which include aspects related to equipment, settings, angles, distance, backdrops, and editing [2]. This concept is particularly important when generating high-quality images that need to be used for algorithm analysis. Although we should ideally be sharing standards among specialties like plastic surgery, orthopedics, dermatology, and wound care, the reality is that these are still in its infancy [1].

Furthermore, when one has a look at photographs in medical books and papers, where the best is being shown, one can see that little attention tends to be given to this important subject.

For surgical patients, a basic requirement of documentation is (a) taking a photograph before biopsy/presurgery; (b) one right before surgery if marked margins want to be registered; and (c) one after surgery. Preoperative, operative, and postoperative images should be technically comparable with respect to attributes like image exposure, light, composition, and posing. This lack of consistency has been reported in different works like Uzun M [3], Wu T [4], and Wyatt KD [5] where color, white balance, position, sharpness, lack of proper background, and depth of field are the commonest flaws. A correct presurgical photograph is a requirement when the surgery or biopsy is going to be performed by another surgeon as it helps locate the lesion that was selected to be removed [6, 7].

There are technical requirements for the patients, for the camera, and for the space where the photographs will be taken.

14.2 Technical Requirements

Standardizing requires following a list of directions—a checklist—which includes aspects that relate to the patient, to the equipment, and to the setting.

14.2.1 The Patient

A proper preparation of the patient will save time and spare some common errors.

Keep a checklist at hand and make sure all these points have been considered:

- Remove makeup and sun protecting creams (Fig. 14.1).
- Remove soiled bandages.
- Clean the skin if needed.
- Remove jewelry and glasses.
- Keep hair in place using diadems if necessary or tying the hair back (ponytails).
- Remove clothing. Avoid photographing patient's clothes (partial or total). Use modesty garments whenever necessary. These can be bought in specialized stores. The patient should not feel uncomfortable.
- In nail photography: remove nail polish.
- Avoid when possible photographing areas with tattoos, scars, or birthmarks. De-identification should be pursued whenever possible.
- Posing: give clear instructions in regard to posing. Help yourself with posing charts. Explain what is expected in regard to position.

Fig. 14.1 Portrait with (left) and without (right) makeup

- Before a photographic session, let the patient rest in a fresh room at a comfortable temperature. Let the skin acquire the normal tone and temperature (redness from excess heat outside or extreme cold, sweat, etc.).
- In patients with reduced mobility, help them with posing.

14.2.2 The Equipment

The selection on the type of camera has been covered in the chapter on Equipment. Once you decide which camera to use, it is recommended that you do not change the equipment during the entire operative procedure (pre-, postop, and future follow-up; during monitoring of a skin condition). The same will hold true for the lens on the camera and the light source. Different cameras have different optical systems, sensors, processors and even different mechanisms of capturing an image. This directly affects their color reproduction capacity, their dynamic range and even their sensitivity to light. Thus changing cameras will not give comparable images. Different cameras and different techniques can create images that falsely create changes in appearance [1, 8].

The basic equipment is:

- Camera
  - Color Calibration: picture style or picture control also controls image colors to a great extent and must be set to neutral.
  - Lighting: natural light, flash, lateral monolights.
  - Exposure Triangle: lens type, magnification ratio, shutter speed, ISO.
  - Focus: manual, semiautomatic, automatic.
  - Resolution: RAW, JPEG.
- Lens flashlights: built-in, ring flash, external.
- Tripod
- Accessories: dermoscopes, cheek retractors, and contrastors (black metallic instruments that block unwanted details during intraoral photography) [9] as well as designed intraoral mirrors
- Scale to include in the photograph

The photographer needs to know:

14.2.3 Image Composition

- Image Orientation: landscape (horizontal) vs vertical
- Field of View: close-up (just the lesion); medium view (area where the lesion is located); large or full view (entire body)

14.3 The Settings

For the physical area or photography room (see Chap. 10):

- Backgrounds: remove or hide distractions (bed sheets, doorways, medical instruments).
- Backdrops: cotton backdrops are great if you need to move from one area to another for photographing (velour is great, muslin is another option). Place it flat, with no creases. Paper needs to be seamless.
- Backdrop support.
- Marks on the floor indicate the constant distance to the patient; marks on the walls to indicate where the patient should look.
- Chairs/stool.
- Monitors.
- Placing mat: for patient positioning.

Let us elaborate on some of these topics.

14.3.1 Equipment

It is recommended to use your interchangable lens camera on manual mode because you can make settings according to your requirement and keep them consistent throughout our documentation protocol by keeping note of it. This is not possible in automatic or semiautomatic modes because the camera decides the settings for a particular image. Hence if the ambient lighting condition or the relative position of the patient and the operator (photographer) changes, the settings will change automatically, and the images might be inconsistent. Setting the camera on manual mode and maintaining constant settings is hence the ideal technique for any form of documentation.

Keeping the camera on the manual mode gives control of settings in accordance to your subjective requirement such as:

(a) Exploiting the depth of field to the maximum
(b) Not being affected by the ambient light source

Any camera on automatic mode or semiautomatic mode fails frequently to do this because it does not understand our subjective requirement as most cameras are made for the general population and not specifically for a clinician. This is why it is important to understand the difference between good exposure and correct exposure. Any image can be made in many exposures; what looks perfect is a very subjective decision, and we cannot rely on the camera to make the expected adjustments.

For example, if you take a close-up image of the teeth and gingiva, the camera will give a particular exposure. A camera on automatic or semiautomatic mode does not however understand whether the exposure was for the teeth or for the gingiva, and it might give us an exposure in between also called *average exposure*. (One could control the amount of area the camera meters to give an exposure, but what the camera delivers might not be according to your expectations).

If the camera is kept on manual mode we have to make adjustments to its settings in order to get a good exposure. The three most important settings that control image exposure are shutter speed, ISO and aperture (f-number). Together they form the components of the ever important exposure triangle.

As a clinician one would want:

- A deep depth of field for sharper images. A high f-number (aperture) will give a deep DoF; by using a fast shutter speed, motion blur will be prevented, and by keeping the lowest ISO, image noise is restricted to minimum.
- The lowest ISO, is 100 in most cameras.
- The fastest shutter speed when flash is used, could be around 1/100 to 1/250 depending upon the camera model.

If you are covering a small area and flash is used (close-up macro photography), go as high as f/32 or more. For larger areas (field of view), move away from the subject which calls for a reduction or compensation of the f-number by going down to f/18 or less. It is however recommended not to choose very low f-values (below f/8) because the depth of field becomes shallow.

It is of significance to note that in general one cannot change the f-number on most smartphone cameras or even if they can, there is no provision to use f numbers as high as f 25–f 32.

14.4 Color Calibration and Lighting

Unless you want to adjust the settings of your camera for each ambient light change, use flash or external lights to take photographs with reproducible conditions.

Natural light can have advantages. It maintains shadows and the sense of tridimensionality. It is ideal for acne scars or wrinkles. Flashlight tends to "flatten" the image; there is a loss of shadows and skin tone whitening in addition to reflection. Using natural light has the disadvantage that light temperature changes continuously and it is very difficult to take comparable images. Also since the ambient light is not as powerful, one is compromised to keep the f-number low, so the depth of field is less or ISO has to be increased which causes image noise.

A flashlight emits light at a constant temperature at around 5000 K. The ideal lighting is broad-spectrum lighting although it is not easily available. If studio floodlights are used (diffused by umbrellas or soft boxes), they should be positioned at 45° to each other on each side of the camera and slightly above the area to be photographed, 1–1.5 m in front of the patient. Back lighting may be used to eliminate shadows [10, 11].

14.4.1 Why Use a Flash for Documentation?

Using a good flash for clinical documentation is important because:

1. High f-number can be set on the camera. Higher "f" means less light enters the camera through a smaller aperture size inside the lens but deeper DoF is possible. Flash compensates for the reduction of incoming light.
2. It allows working with low ISO values which results in clear noise-free images.
3. It reduces or negates the effect of ambient light on your documentation, thereby giving better consistency in color reproduction. Ambient light changes continuously in temperature, and photos taken with daylight or under different sources of artificial light need to be adjusted for color (white balance).
4. It leaves your settings to remain more or less standard with very little changes required.
5. It simplifies obtaining a black background without any additional setup. Whenever your ambient light is dimmer than the flashlight, the background gets negated (Fig. 14.2).

14.5 Exposure Triangle

When you use flashlight, a guideline for good settings would be as follows:

- Shutter speed: 1/200.
- ISO 100.
- High f-number (f-number has to be set by the clinician based on the exposure of the first image for example: If the first image at Shutter speed 1/200, ISO 100 and f 25 was dark then take the next image at f 18 keeping the shutter speed and ISO on the previous values itself).
- Flash is usually used on full power when a large area is to be covered. It can be got down to half or one-fourth power for close-up macro images. Flashlight can whiten skin tone, reduce contrast, and cause reflections. Ring flash, diffusers, lateral lights, and intensity reduction can compensate for these issues.

14.6 Focus

Select manual focus over automatic focus.

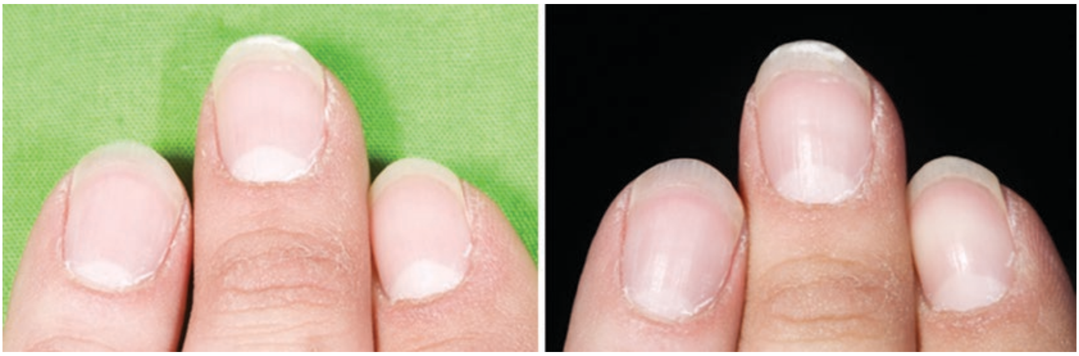

Fig. 14.2 Difference between position and background correlation. The picture on the left was taken placing the three fingers directly over a green backdrop. Notice the shadows and cloth's texture. On the right picture, a black background was achieved by keeping the subject away from the background using high flash power and high f-number

14.7 Resolution

Set your camera at the highest resolution of image. RAW+JPEG is the most commonly suggested setting.

No universally accepted standard currently exists for either spatial or color resolution of camera-acquired digital images of a skin disease [11].

14.8 Standardized Backgrounds

It is disturbing to see preoperative and postoperative images having different backgrounds. For a good documentation, it is recommended to use a plain, texture-free background, one that must remain constant in all images.

The most easily available backgrounds are black, blue, green, or white. It is recommended that if you want to use a cloth behind the subject, the texture of the cloth must not be seen. Photography background paper is another option. Rolls are sold in specialized photography stores. Blue and green are more difficult to work with although some recommend them for darker skin and/or hair tones. Black is another backdrop of choice. It gives contrasted images, and the viewer tends to focalize better at the point of interest. When using a black background, rim lighting is essential, whereas a white or green background should be illuminated evenly [12].

There is a way of obtaining black backgrounds without the need to use a black cloth or paper behind the patient. This saves time and effort. The procedure to obtain such backdrop is the following:

1. Keep the flash on.
2. Keep the subject as far away from any background as possible.
3. Keep the f-number high.
4. Have a dim ambient light.

When the light does not get reflected back from any surface or the light that is reflected is very dim as compared to the one coming from your subject, you invariably get a black background without any additional setup. (Fig. 14.2).

If at all a background is to be used, we recommend using a blur background at a distance from the subject. Separating from the backdrop has the advantage of negating the effects of disturbing shadows on the background. Black is better for this purpose over green or blue which in turn is better than white.

14.9 Image Composition

If the preoperative and postoperative images do not look similar with respect to the area covered and size, then documentation loses its value. Consistency with respect to image composition requires two basic criteria to be met as long as you use a fixed focal length lens like a 100 mm macro lens:

Fig. 14.3 Macro lens showing the magnification ratio and the working distance. 1:1 means that the size of the image in real life is the same size as it is reproduced on the sensor; 1.02 ft (or 0.31 m) is the working distance

1. Distance between the subject and camera has to be kept constant.
2. Angulation with respect to the subject and camera has to be the same.
3. Patient's position needs to be the same.

The camera sensor plane should be parallel to the body part being photographed; otherwise the image can be distorted. Just as the patient needs to be in the right pose, the photographer has to stand in the correct position holding the camera properly.

14.9.1 How Do You Maintain a Fixed Distance from the Subject to the Camera?

The answer to this question is on your lens.

For clinical documentation it is recommended to use a macro lens at all times.

A macro lens is a special type of a prime lens that allows coming close to the subject and making high-magnification images. Macro or micro is basically used for close-up photography because it is designed for a short focusing distance.

Most macro lenses have indications on their dial which refer to the magnification ratio and the working distance (distance between the subject and the camera) in feet and meter (Fig. 14.3). Magnification ratio in digital photography refers to the ratio that exists between the size of the image projected on the sensor and the real size of the object size. A macro lens has the ability to focus from infinity to 1:1 magnification, meaning that the size of the image in real life is the same size as it's reproduced on the sensor [13]. A 1:2 ratio macro can project an image on its sensor up to half the size of the subject; a 5:1 ratio macro can project an image five times the size of the subject.

Full-frame cameras—also called 35 mm format—have a sensor size of 24 by 36 mm.

If you take a photograph of a ruler kept horizontally with a macro lens at 1:1 magnification ratio mounted on a full-frame DSLR, you will be able to see 36 divisions of the ruler's millimeter reading. If instead you set the magnification ratio at 1:2, you will be able to see 72 mm reading of the same ruler (Fig. 14.4).

Let us now change equipment and switch to APS-C cameras. A crop sensor camera has smaller sensor size than full-frame. One example

Fig. 14.4 Photograph of a ruler oriented horizontally. The image shows exactly 36 divisions. It was taken using a Canon EOS 6D (full-frame DSLR) having a sensor size of 24 × 36 mm with a 100 mm macro lens at 1:1 magnification ratio. This means that 1 mm of the ruler is exactly equal to 1 mm of the sensor. This is a 1:1 magnification on a **full-frame** camera

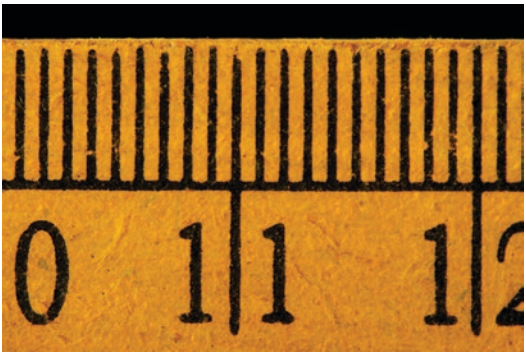

Fig. 14.5 Photograph of a ruler oriented horizontally. The image shows exactly 22 divisions. It was taken using a Canon EOS 700D (crop sensor DSLR) having a sensor size of 18 × 22 mm with a 100 mm macro lens at 1:1 magnification ratio. This means that 1 mm of the ruler is exactly equal to 1 mm of the sensor. This is 1:1 magnification on a **crop** sensor camera

is the 18 × 22 mm sensor. If you use the same lens at the same magnification ratio of 1:1, you will be able to see 22 mm divisions only because the sensor size is smaller. At a magnification ratio of 1:2, we will be able to see 44 divisions (Fig. 14.5).

In clinical photography the magnification ratio holds significant importance for two reasons:

1. It sets a standard distance from which an image has to be made and hence the composition remains standardized.

   If preoperative images are made at a magnification of 1:2, then even the operative and postoperative images have to be made at the same magnification ratio.
2. It is a method of communication with our colleagues. You can register all the data from the settings for your or other's future reference.

14.10 How to Use Magnification Ratio? A Step-by-Step Guide

1. Ensure that your lens is on manual focus.
2. Rotate the focusing ring (which also changes the magnification ratio) to **set the magnification ratio** or distance of your choice.
3. Stand in front of the subject such that the lens is perpendicular and directly pointing to the subject without any up or down canting.
4. Move in close to the lens, and try to appreciate if the subject is becoming sharp or blurred.
5. If the subject is becoming blurred as you move ahead, it means that direction is wrong and that you will have to move backwards to get the subject in focus.
6. As you move behind and appreciate that the subject is becoming sharper, press and hold the shutter release halfway through.
7. As you move behind slowly at one particular point, the subject becomes fully sharp (some cameras also give out a beep sound confirming that the subject is in focus and give a visual indicator like a flickering light or a focus peaking).
8. It is at this point that you have achieved your preset magnification ratio or the distance in feet or meter, and you convert the half shutter release to a full shutter release.
9. You have to note down the magnification ratio at which the images have been documented. When the patient comes for a future follow-up, refer to the magnification ratios that were used previously, set them again by rotating the focusing ring, and follow the same technique of getting your subject into focus.

The audio signal/ flickering/peaking will always come at the same accurate spot even in future. This helps you keep a constant distance between the subject and camera.

While using a full-frame camera:

- An area approximately the size of an adult head will require a magnification ratio to be set at 1:10. (If one does not have 1:10 imprinted, they may use other markers like distance in feet or meter. Typically the full face comes at a distance of 5 ft or 1 m.)
- An area approximately the size of an adult palm is covered at a magnification ratio of 1:3. (Area covered: 72 × 108 mm).
- An area approximately equal to the closed fist is covered at a magnification ratio of 1:2. (Area covered is 48 × 72 mm).
- The maximum magnification in most of any macro lens is usually 1:1. At 1:1 the area covered will be 24 × 36 mm.

A mark on the floor for the patient and for your most commonly used standing position will simplify and speed up your routine.

14.10.1 Macro Lens

Macro lenses are special prime lenses with a fixed focal length. Choosing a macro lens from the large selection commercially available can be challenging. Before deciding which focal length will suit you better, you need to take into consideration several aspects including the space of your consultation.

There are aspects specific to the lens:

1. Angle of view: the lesser the focal length, the greater is the angle of view, and more area will be seen or covered in front of the lens/camera. In other words focal length is inversely proportional to the angle of view.
2. Distortion: focal length is inversely proportional to distortion.
3. Minimum focusing distance: focal length is directly proportional to minimum focusing distance.

Taking all the above into consideration, if a clinician wants to avoid distortion in images, then the ideal choice for a macro lens will be 100 mm which is more on the telephoto side; however, if full body images are to be made, the distance between the subject and the camera will be quite large and hence suitable only for large consultation spaces. A 100 mm macro lens is ideal for close-up images of small areas like one-third of the body or the head, palm, eye, or fingernails.

For a clinician who records full body images on a routine basis and has to work from a small room, a 100 mm lens might be a bit difficult to use. A lower-focal length macro lens like 35 mm or 50 mm might be a better choice. It must however be noted that these lenses might not be a good choice for recording smaller areas like fingernails or intraoral lesions because the image might suffer from fisheye effect (barrel distortion) and might not be useful for publication or scientific usage.

Another aspect to consider here is that for clinicians recording full body images on a regular basis, powerful flashes might be a good choice as compared to typical ring flash or built-in camera flash. A separate photography room with a neutral background color paper and studio will be an ideal setup for documenting cases.

14.10.2 Field of View

When recording lesions keep in mind to record:

1. Global (Large or Distant view). Wide-angle shot covering a large area. This gives information of what body part is affected, whether the lesion is unilateral or bilateral. It is the type of view for generalized inflammatory skin conditions like psoriasis.
2. Medium View. It includes the lesion and all margins or full extremity. It is ideal to give a sense of the size of the lesion in relation to the area of the body that is affected (for a tumor on a cheek, a medium view would include the whole face or at least half face and for a herpes zoster infection, the whole area with lesions and the contralateral lesion-free area).
3. Close-Up View (High Magnification at 1:1). It will reproduce finer details of the lesion (Figs. 14.6, 14.7, and 14.8).

		Field of View		
Requirements		Single lesion	Localized lesion(s) (i.e. metameric)	Generalized lesions
	Close up	√	√	√
	Medium View	√	√	x/√ (not essencial)
	Distant View	X	√ (helps to determine symmetry/ assimetry)	√

Fig. 14.6 Requirements for image taking depend on the type of lesion. The required field of view is specified per lesion type

Fig. 14.7 Examples of field of views. Far left, distant view; center right, partial long distance; medium view; far right, close-up view

14.11 Posing

Sequential imaging protocol is necessary when you need to monitor or do a pre- and postoperative control. Once camera, flash and lighting, focus, distance, and backdrop are under control, posing is an important part of standardization that poses its own challenges.

Poses are an important aspect of getting an image standardized. Incorrect positioning can lead to visual misinterpretation. Frontal facial views require the same magnification ratio and same position of the head. If the face is tilted up or down, the images will not be comparable. It is important to ask the patient to place the head over a plastic gadget made for such purpose (Fig. 14.9) which is similar to the one used by ophthalmologists when examining the eyes. Other standard positions for the head are shown in Fig. 14.10. Note that the patient will need instructions on how to stand (feet position is shown in yellow in the picture) and how to place the face following the Frankfort horizontal plane.

Head position for hair photography is mentioned in the chapter on Nail and Hair Photography.

Other standardized positions for medium and distant views are shown in (Figs. 14.11, 14.12, 14.13, and 14.14). It is helpful to have at hand a drawing with the anatomical planes like the one seen in Fig. 14.15. Here you can also see an example of a photograph of legs (front and back) with different background colors.

To get the patient in the correct position on the first visit and in follow-up visits, use a mat, or build it yourself (an octagon wood block with the numbers indicating the positions required to the patient). Take some time explaining what you expect and how you want the patient to pose.

Fig. 14.8 Plastic gadget to place the head in position

Prepare the patient. You or the person in charge of taking the photographs needs to carefully explain to the patient what is expected from them. Encourage proper posture and request the subject to look straight. If you need to take many pictures or from an area where the patient needs to maintain uncomfortable positions (like oral photography or standing up in elderly), be calm and give your patient time to rest. Use illustrated charts or posters to show the patient the expected pose. You might also need to set the patient into a position where a lesion is better visualized (Fig. 14.16).

Identification of laterality is extremely important whenever the image is used to indicate the preoperative site for a biopsy, surgical procedure, or follow-up of an isolated lesion. Care should be taken as images are sometimes flipped when stored.

14.12 Scale

The presence of a ruler might be important especially when photographing tumors or in surgical procedures in general. Eskiizmir found that fron-

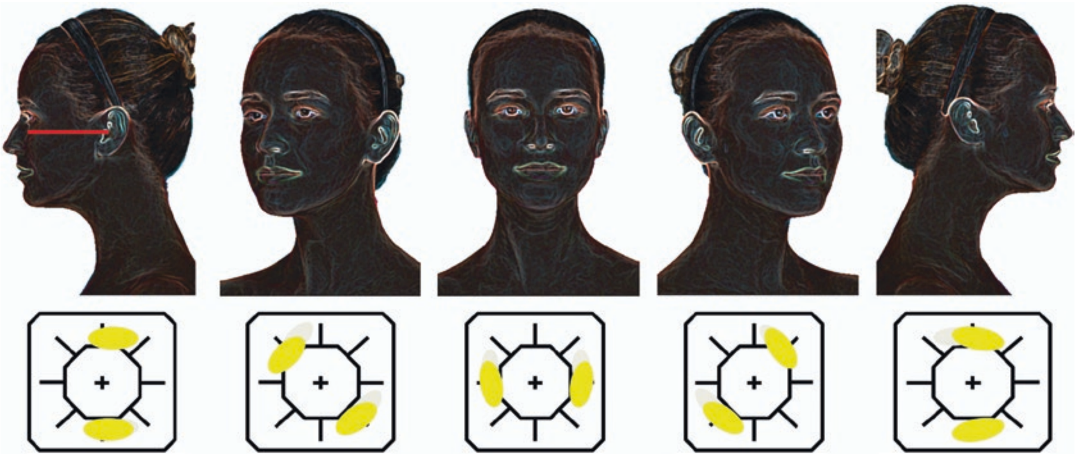

Fig. 14.9 Standard face position obtained by placing the patient over a positioning mat. The yellow ovals represent the feet's position. Place the face following the Frankfort horizontal plane (see red line on the far-left picture). This line is the proper angle to take profile images. It is drawn from the ear canal to the bony ridge under the eye (infraorbital rim)

Fig. 14.10 A set of images showing knees and elbows, ideal for monitoring patients with psoriasis

Fig. 14.11 Photograph of both axillas and right axilla

tal and close-up views are not adequate to represent the size of the lesions and that metric view may give a better representation [14]. Rulers should be matte finish, have no brand names or patient identification on it, and preferably placed directly on the skin to avoid distortions (Fig. 14.17). Make sure the lesion and ruler are both in focus. Using a digital scale is ideal when in need to add the measurement in the picture. They avoid all the inconveniences of a physical ruler [15].

14.13 Photographing Children

Taking clinical pictures of children is always a real challenge just as it is for nonmedical photography. Kids tend to move, can be restless and cranky, and are simply not in the mood to pose for a medical photography especially if unwell. Special considerations and extra effort are required as well as lots of patience. All should have a chaperone (family or staff); providing toys helps distracting them; if seating is needed, use

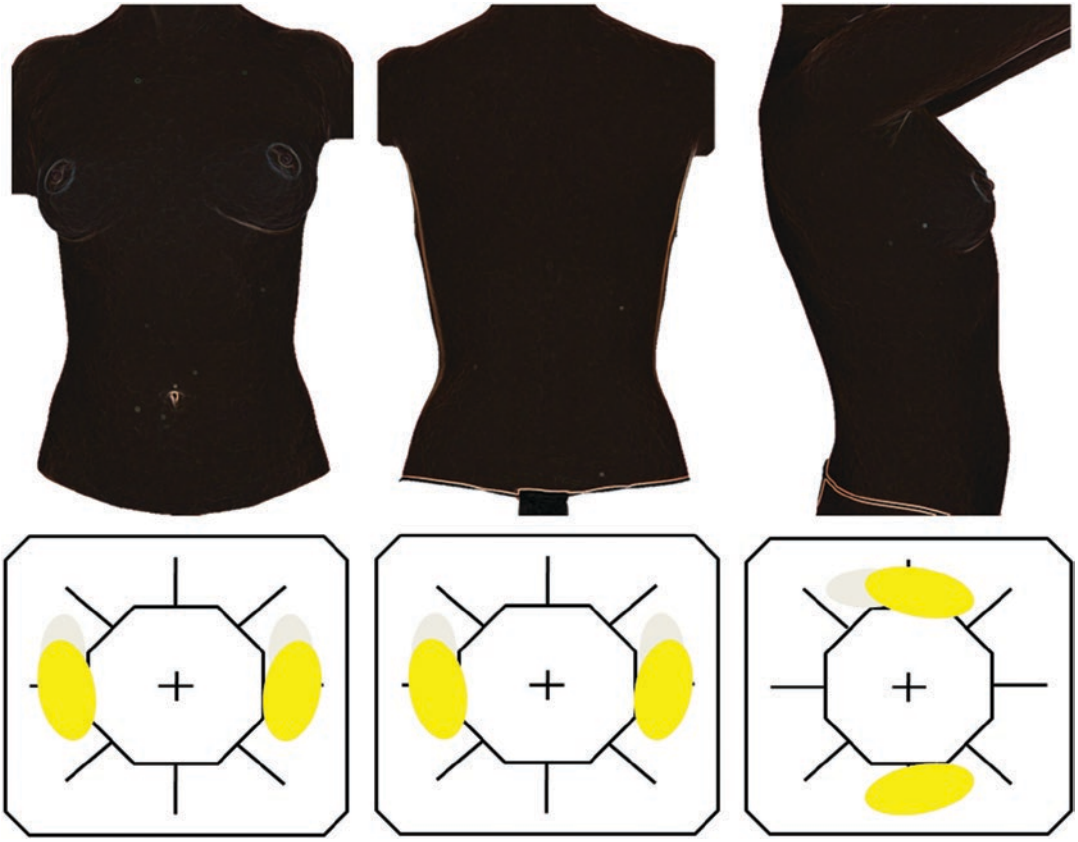

Fig. 14.12 Positioning of the trunk: (left) front, (center) back; (right) lateral right as indicated on the mat. The yellow color indicates the position for the feet

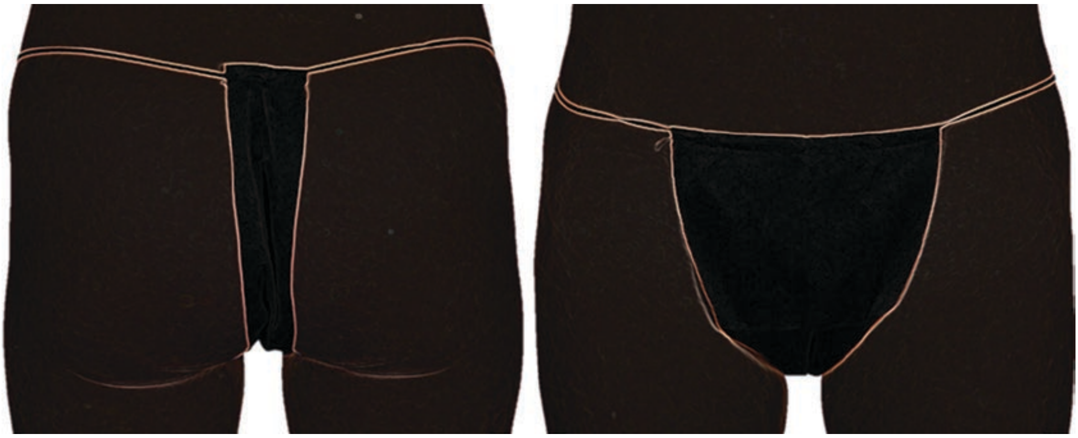

Fig. 14.13 Position for the buttocks (left) and genitalia (right)

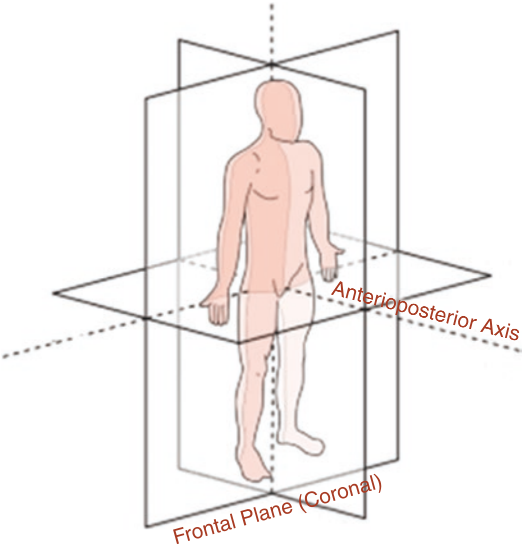

Fig. 14.14 Anatomical planes to help position the patient correctly

small stools: children need to be placed in a low-seating position. For a throughout review, see IMI Guidelines on Pediatric Photography [16]. Keep the studio at the correct temperature, especially in winter time. Undressing a baby has to be done in a warm pleasant room. Keep the camera strapped onto you to avoid accidental dropping over the child.

Standardization is particularly important as some conditions will be photographed over the years.

14.14 Chaperone [17]

A chaperone is a person who is present during a procedure as a safeguard for all parties (patient and clinical photographer) and is a witness to the continuing consent of the procedure [17].

Fig. 14.15 Photography of front and back legs with different background colors

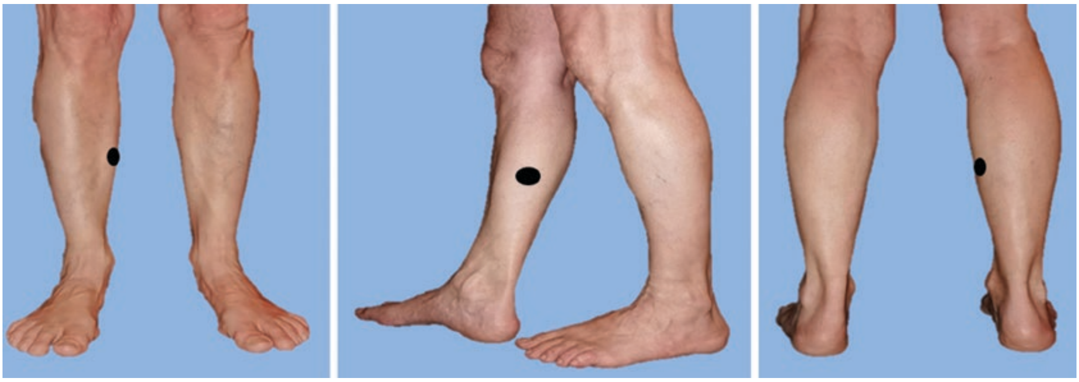

Fig. 14.16 Changing positions to visualize a lesion that would not be seen using the standard position

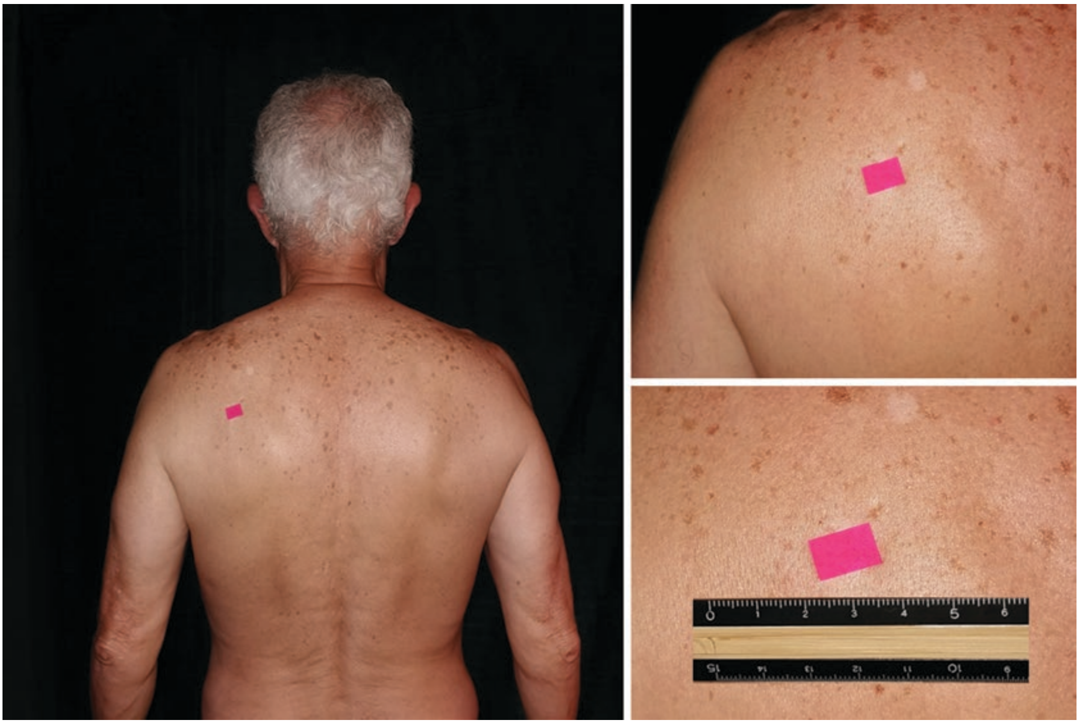

Fig. 14.17 Left, distant view; top right, medium view; bottom right, close-up view, including a scale to know the size of the lesion

The main function is to safeguard all those involved in the photography procedure. They can be informal chaperones (family or friend) or formal (a staff member). They should be present whenever children and mentally impaired patients are in an unconscious or semi-unconscious state or when intimate areas are to be photographed. They sometimes function as interpreters whenever there is a language barrier or other communication barriers and in cultural diversity situations.

14.15 Wheelchaired/Handicapped/Patients with Reduced Mobility

When photographing people with physical impairment, one should avoid generating inconveniences to the patient. Mobilizing a wheelchaired person into a photographic preset area generates unnecessary discomfort. It is the studio that needs to be adapted to the patient and not vice versa. One option for portraits is to have a wheeled stand with a cloth hanging from it and a bib of the same color. In Fig. 14.18, the patient was not moved from her wheelchair, and a good photograph was taken, hiding all distractions (background and clothing) and without generating discomfort to the patient. A black velour backdrop placed on a wheeled stand and a velour bib were all it was needed.

Bedridden patients pose a challenge as it is sometimes difficult to place them in the correct position. Clean the area to be photographed by removing blood stains and gauzes and tapes that are covering the region of interest (ROI). Try to place the patient, when possible, in the correct anatomical position, and place a disposable backdrop under the ROI (sterile disposable camera drapes can do the job). Move away sheets, blankets and pajamas. An effort should be made by the photographer to take the picture following standardizing requirements, if the patient conditions allow it. It is an extra effort that will result in proper images.

14.16 Wound Photography

In wound monitoring, photographs are taken to assess progress [18, 19]. Acute lesions should be photographed with every dressing change while chronic ones every 2–4 weeks (depending on the anatomical area, i.e., chronic leg lesions tend to be the slowest to progress). Just as with dermoscopic photography, the lesions should be cleaned and crusts removed to allow visualizing the underlying tissue. See IMI guidelines on Wound Management Photography [20].

Wound photography has proven useful for monitoring from both the healthcare personnel and the patients who get more involved in the management of the lesion particularly for difficult-to-see wounds [21].

14.17 Photographing Sensitive Areas

Undressing can be unfordable for some. If now one adds to nudeness the possibility of photographing and permanently uploading the image into a health record or sharing it with colleagues, then the initial discomfort can turn into anxiety and rejection. Taking photographs of certain areas of the body can raise concerns. The face is probably the most sensitive area for many. The sensitivity is determined mostly cultural or personal: photographing an uncovered head can be an issue if the subject is a Muslim woman; male breasts are not included as a sensitive area by

Fig. 14.18 Portrait of a wheelchaired person using a velour backdrop and bib

most cultures, but for some (not all) cultures, women's breast photography can be a concern. Even within a human group or a person in different periods of life, there might be differences. Therefore, it is best to first speak to the patient and ask if photographing that certain area generates discomfort. We could find that sensitivity is different and can be related to genitalia, anal region, breasts, breastmarks, a disfigured part of the body, the uncovered head, or naked feet. If such is the case, consent from the patient, reassurance, chaperone inclusion in the photographing session, and complete de-identification should be pursued. With regard to facial photographs, "masking" or placing dark bars over the eyes, nose, or mouth not only can cover areas of interest but also generate a distraction in itself and can be of no impact on their original purpose of de-identification [22].

For the breast area, some guidelines have been published by IMI (Institute of Medical Illustrators) available at their website [12].

14.18 Other Special Sites

IMI (Institute of Medical Illustrators) Guidelines for non-accidental injuries [23], cleft lip palate [24], scoliosis [25], wound management [20], rhinoplasty [26], and breast photography [12] include deeper notions on each of these specific subjects.

14.19 Teledermatology Standards

Teledermatology (TD) is a subspecialty of dermatology that uses telecommunication technologies to transfer medical information over varying distances. This information can be data and sometimes audio, and mostly it is visual. Photographs of patients/lesions in patients are sent via systems integrated into public or private health systems, apps, or social media. Unlike a face-to-face consultation where the patient is seen, probably diagnosed and then photographed, in teledermatology it is the opposite: the patient is photographed and then diagnosed. Most studies show comparable diagnostic accuracy between teledermatology and face-to-face (FTF) care with some showing TD superiority and others inferiority [27]. By setting the FTF as the gold standard, studies will be needed to understand the accuracy of FTF among different dermatologists before comparing it to TD.

This centers the focus on photography: the image taken needs to be of excellent quality. As metadata (attached information on the image) is limited, the diagnoses are mostly done by looking at images. In skin cancer triage and mole monitoring, the inclusion of a dermoscopic image is a requirement as it gives the additional and pivotal information on the lesion, allowing the specialist to rule out malignancy and decide the appropriate management (surgical, follow-up, or simply confirm benignity) [28].

The complication comes because the image is usually taken by a third party (another physician, nurse, patient, or caretaker).

By transferring the responsibility for obtaining the most important diagnostic piece, there is a risk that the image obtained will not be of quality. Bad image quality is still an issue in some centers [28], ranging in occurrence from merely 2–3% up to 10–15%.

A study trying to determine if a previously instructed patient on basic photography could take better images and improve accuracy of diagnosis showed that the group with instructions had increased average image quality with no statistical difference in diagnostic concordance. An interesting point was that diagnostic accuracy varied by diagnostic category, hair conditions being the one with the lowest accuracy [29].

When setting a TD system (primary, secondary, direct to consumer, or patient-assisted), it would be useful to give short and concise instructions on image capturing. Spending some initial time training family physicians or nurses or including in derm app brief instructions on how to take the correct image will result in better-quality images. Although further studies are needed, a better image should improve diagnostic accuracy. Some apps like MySkinSelfie [30] include a photo guide to help posing the affected area by showing a “ghosting” image of the previous photo. Imagine from LEO Innovation Lab also includes a “ghosting aid” [31].

14.20 Standard Editing Protocol

Photography and its equipment have come a long way since inception and so have editing protocols and techniques. The equipment now produces very high-resolution images which require powerful dedicated software for postprocessing.

Every camera first produces a RAW file which can then be converted to a more usable format postediting. In mobile phones the raw file is usually discarded because the RAW files take up a lot of space owing to their huge file size as compared to compressed JPEG (or JPG) files. In cameras, there is an option to save or discard the RAW file under the option of image quality in the menu. We must always store and use the RAW file for editing. The file important for us during the editing process is the RAW file because RAW editing is pixel-based editing as compared to JPEG editing which happens in layers (also called the digital negative or .dng file). RAW files are lossless compressed files but just like a negative cannot be used as a final image and have to be “developed” into a positive. A RAW file needs to be converted to other formats for them to be used as an image. As the name suggests, they are “raw” files and might need some editing into a useful image. In the market there are editing software like Aperture, Adobe Lightroom, Adobe Camera Raw, Capture One, etc. that are capable of editing RAW files and bring out the best details to make them look more polished and professional for a particular image requirement. Editing has to be done with the end result or output format in question. For example, if the image is going to be printed on a matte paper, we will edit the image to be slightly overexposed (more bright) to compensate for the printing ink being absorbed by paper as compared to editing for a presentation to be done on a LED screen in a conference where we would probably keep the images correctly exposed and not overcompensated as we do for printing.

Another aspect to be taken into consideration when making images from RAW format is that we can correct many settings during the postprocessing that cannot be done when using JPEG files. For example, if we have made an image using incorrect white balance or picture style during the documentation process, it can still be corrected during editing using RAW editing software. This cannot be done using JPEG files.

The most important feature to be considered during editing is during cropping and rotation.

Here we encounter another ratio called aspect ratio.

Aspect ratio is nothing but the ratio between the width and height of the image.

When cropping it is imperative that we lock the aspect ratio according to our desired composition before we start cropping. When and if needed to crop, it is important to maintain the same aspect ratio in every image family. Freehand cropping is contraindicated as it will lead to different sizes and shapes of output images.

If we are cropping the preoperative image at an aspect ratio of 16:9, it is recommended that all future images be cropped at the same aspect ratio to maintain standardization.

When we make an image collage of all the images together, we shall come to know about the possible errors that have occurred while documenting the image or during its postprocessing. Thus, making collages of images will help achieve consistency and standardization of our documented cases.

14.21 Conclusions

There are working groups developing standardized attributes and workflow-related modifications to support identifying and describing patients from different medical specialties. Surprisingly enough, dermatology—a specialty that generates among the largest numbers of medical images—is not among these [32]. For the best benefit of patients, guidelines need to be created to help physicians from any part of the world to create images following standardized criteria.

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15

Special Considerations: Nail Photography

Kingshuk Chatterjee and Paola Pasquali

Contents

15.1 Introduction

Nail changes and diseases of the nail unit have always been of great interest to physicians, particularly dermatologists, rheumatologists, and internists. Not only they can depict signs of local conditions as well as internal diseases, but also evolution of nail changes can predict prognosis and treatment response for many diseases. Imaging of the nail unit is therefore an important part of cutaneous examination of a patient. Digital photography forms the principal component of this process, aided by other techniques like dermoscopy, capillary microscopy, and ultrasonography.

Capturing a tack sharp image of a nail unit is challenging in many ways. Some of them are:

1. Capturing all the finger and toe nails in a single frame. Trying to place all your 10 fingernails in view leaves the thumbnail partially covered. Toe nails are simpler to pose in one frame although the little finger can be sometimes only partially viewed. Hands and feet can be affected by deformities of the joints making posing challenging. Fingernails are extremely difficult because the plane of the thumb is different from the other fingers. This problem is further complicated in people with arthritis or other bone conditions where finger flexibility is reduced.

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2. Tackling the uneven light bounce due to curved surface of nail. It is important to avoid strong reflections from the nail surface [1].
3. Correct demarcation of the nail change with respect to the reflective surface of the nail.

This chapter intends to help the readers to click sharp pictures of the nail unit for documentation and publication.

15.2 The First Step Before Photography: Respect and Consent

Since the nail unit might not contribute directly into revealing identity of an individual, it is generally perceived that consent is not necessary as far as nail photography is concerned, but a written informed consent indicates a respect for autonomy of the patient as well as saves the physician from litigations in the event of an unpleasant patient–doctor relationship. Content of the consent forms may vary between different centers, but it is always useful to get it approved by the local ethics committee. Some important contents of the consent form are:

1. Purpose of photography (documentation/publication/advertisement of skill).
2. Confidentiality (an aspect of relevance when recognizable features are present like tattoo, scars, or deformities that might give away identity of a particular person).
3. Risk of not giving consent.
4. Policy of sharing photographs with the patient.
5. Explanation in vernacular language in which the patient is proficient.
6. Signatures of patient/legal authorized representative (LAR), the doctor and witnesses, unrelated to both the parties.

Nails are especially non-sensitive areas to photograph, and therefore, its imaging should not generate any ethical or legal problems; however, it is important to remove rings or bracelets whenever possible in order to avoid leaving any recognizable elements and allowing a better standardization of the image.

15.3 The Gadgets and Technical Titbits

15.3.1 Cameras

They can broadly be classified into two categories:

1. Dedicated digital camera (digital single-lens reflex/mirrorless/compact)
2. Integrated camera of a smartphone/digital tablet

While cost, ease of use, and mobility make the second group hugely popular among users, a dedicated digital camera always scores over the former in terms of image quality, control over aperture, shutter speed, depth of field, manual focus selection, and lighting [2].

15.3.2 Light/Flash

As nail photography comes under “Macro” imaging category, it is always better to use a flash/speedlight instead of ambient light. A speedlight ensures good depth of field to get the nail(s) in sharp focus as well as maintains uniformity in color tone of pre- and post-photographs. An external ring/twin flash or lateral lights placed on both sides at 45° are preferable over the in-built camera as they offer the advantage of lighting the subject from different angles, thus preventing development of shadows due to unidirectional lights from in-built camera flash/external speedlights.

Fixed flashes are not desirable because the light hits the center of the subject leaving a “burn” (whitening) effect. Built-in flashes need to be adjusted because the distance to the subject is usually short. To reduce brightness, flash diffusers can be of great help. For built-in flashes, the tip could be covered with a paper tape, the resulting pictures are excellent and highly repeatable series are possible [3]. The use of flashlight will warranty the same amount of light/brightness as it has a constant power and temperature color (5550 K) while ambient light changes continuously during the day. With daylight, shadow control is more difficult.

Studio lighting systems offer the best solution if space permits. They should be ideally used with distancing systems and patient positioning mats and colored backgrounds. Lateral lights placed on each side avoid shadows and central shining.

15.3.3 Distance

A standard distance of the subject from camera ensures uniformity in pre- and post-treatment photographs. Working following the magnification ratio of the lens will help you maintain the proper distance. Keeping the hands on a solid surface like on a table or feet together on the floor keeps the subject fixed. Using the camera mounted on a tripod also aids in keeping the distance fixed [4]. Some new camera models have integrated ranging lights to assure perfect camera-to-subject distance for every picture or laser lights to indicate the correct distance.

If ambience light is dimmer than the flash, shooting maintaining the hands of the subject at a distance from the background will “erase” (blacken) the background. In this case, you would need to place the camera between the patient and the hands (Fig. 15.1).

15.3.4 Lenses: Zoom vs Fixed Focal or Prime Lenses

Macro prime lenses with at least 1:1 magnification ratio are ideal for nail photography. Choice of focal length depends upon sensor size of the camera. Currently, the available cameras use three types of sensors:

1. Full frame or 35 mm equivalent
2. APS-C (roughly 23 × 15 mm)
3. Micro Four Thirds (roughly 17 × 13 mm)

Here comes a little math of crop factor as far as focal length of the lens is concerned. The crop factors are 1, 1.6, and 2, respectively, for the aforementioned sensors. So a 100-mm lens on a full frame will be equivalent to 62.5 mm for an APS-C sensor and 50 mm for a Micro Four Thirds. Zoom lenses should not be used for nail

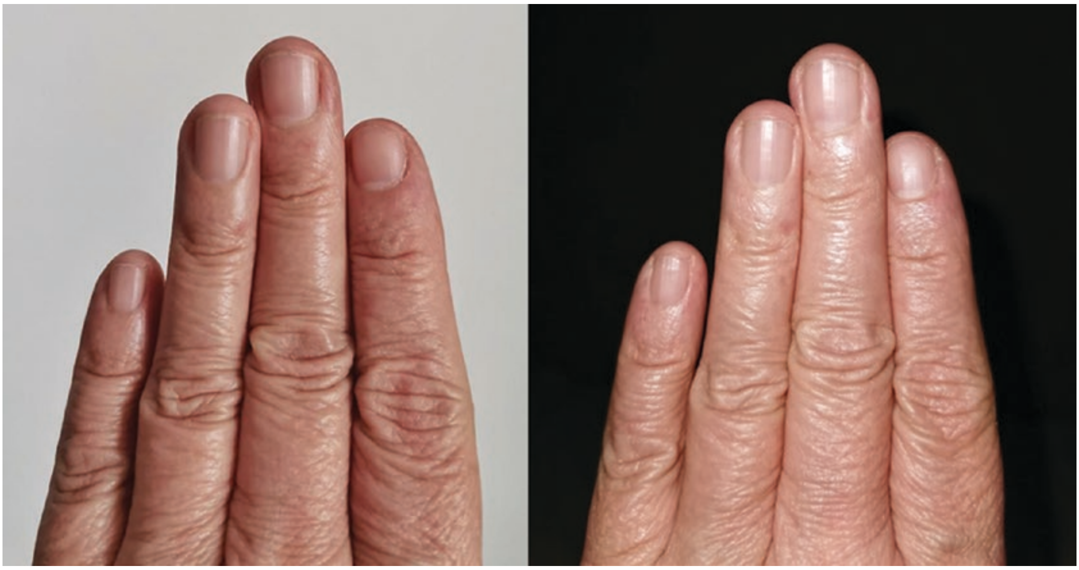

Fig. 15.1 (Left) Image taken in daylight over white background. See the shadows and the reflex of the light coming from the right side. In addition, light background makes the skin look darker. (Right) Built-in flash, with the same background, taken with dimmer ambience light. The background “disappears.” Note the whitening from the flash over the nail plate and the loss of shadows. In addition, the skin looks lighter

photography as they do not provide a good depth of field, and it is difficult to maintain a fixed focusing distance during pre and post photographs. Prime lenses are an excellent option and should take in a 35 mm film—equivalent, 50–60 mm focal length [5].

Depth of field (DoF), also called *focus range* or *effective focus range*, is the distance between the closest and the farthest objects in a scene that appear sharp in an image. If in need to "isolate" subjects from the background, use shallow DOF (emphasize the subject and de-emphasize the background). Narrow apertures will result in greater depth of field [6]. A larger F-stop number (which actually means a smaller aperture opening) will result in a larger DoF [7]. A large DoF will give you images where all fingers or toes will be in focus.

15.3.5 White Balance

White balance (WB) is the process of removing unrealistic color casts [8]. By using flashlight, the temperature color is maintained.

15.4 Technique of Nail Photography

15.4.1 Hand Position: Consistency

There are no standard guidelines for imaging nails. Ideally, all nails should be visualized in a single frame (Fig. 15.2); however, flexing the digits might not be a simple task for some patients. To overcome these difficulties, a two-frame composition has been proposed: one including all fingernails excluding thumbs and a second is created of only the thumbs. Later, a panel/collage is created [9, 10] (Fig. 15.3). This proposal has the disadvantage of a need to create a post processing collage, but the advantage is in positioning the patient, especially for those with reduced mobility of joints. If such positioning was chosen, it could be helpful to have at hand a chart with finger position in order to have the patient place the fingers in the same position when photography is going to be taken in different time periods (Fig. 15.4). Furthermore, standardization of images is easier than with any other position [11]. Gupta et al.'s proposal [10]

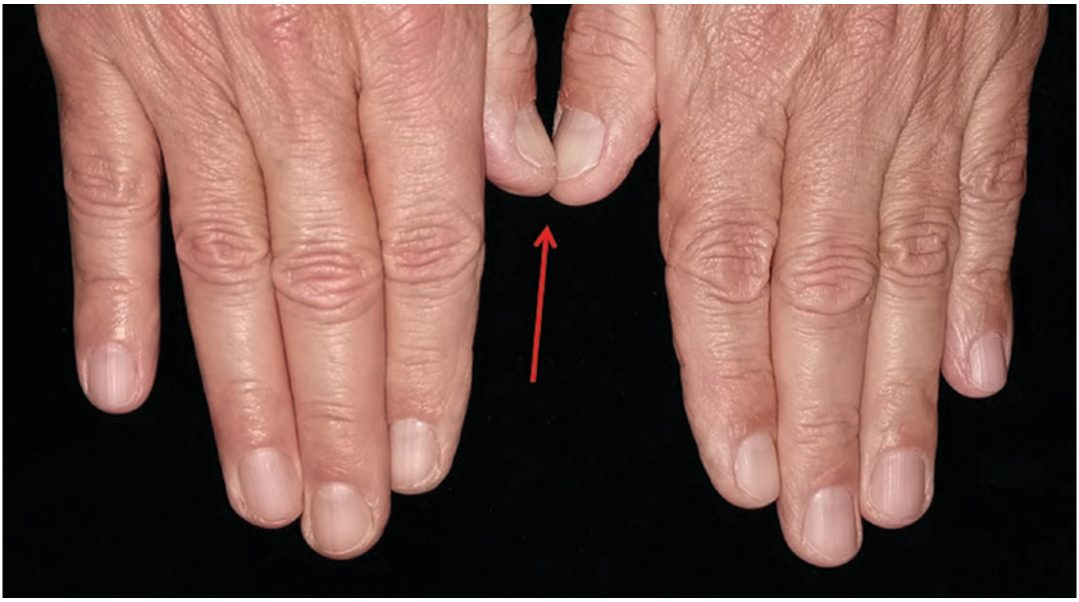

Fig. 15.2 Ideally, all nails should be visualized on a single frame; however, thumbnail view is limited in this position (red arrow)

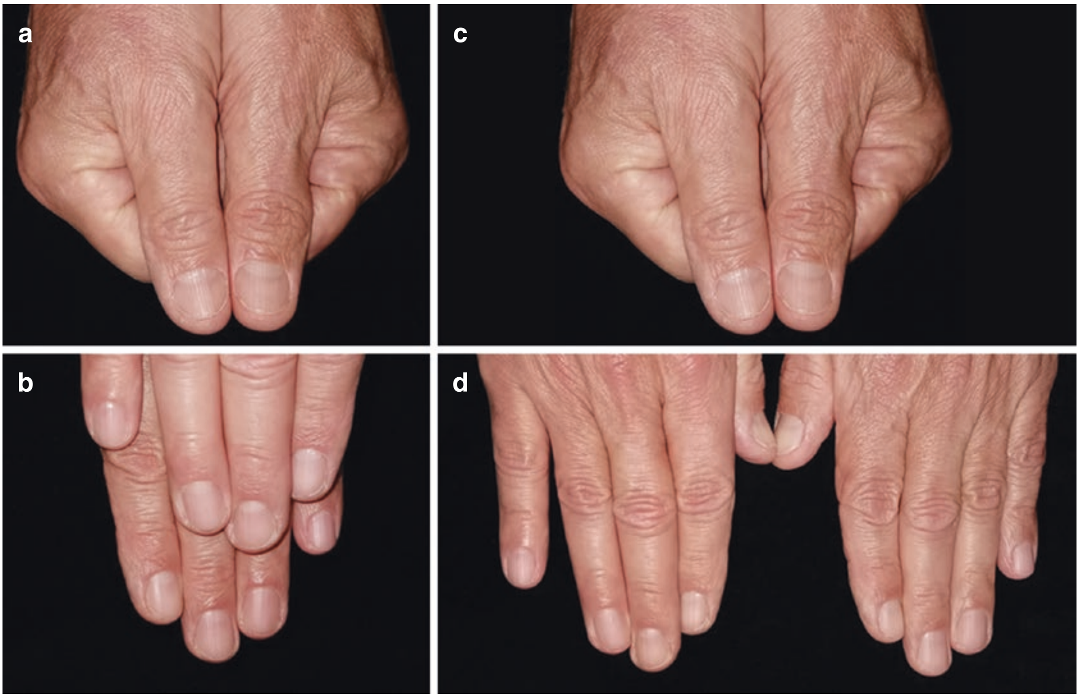

Fig. 15.3 Taking two different frames gives the opportunity to include all nails. On the left side (**a**, **b**): the top image show both thumbnails (**a**) while the bottom image shows the other 8 finger nails with one hand placed on top of the other. The advantage is that the area of focus for the bottom image (8 nail-image) is smaller. The disadvantage is that a deeper DoF is requires as fingers are placed at different levels. On the right side (**c** and **d**): a broader area (**d**) is involved with the advantage of having all nails at the same level. In both cases, a time consuming composition is required

Fig. 15.4 For monitoring, you can simplify finger's positioning by creating a "phantom" image from the original photograph, print it (maintaining the scale), and have the patient place their fingers in the exact position

of keeping hands one over the other allows to visualize all 8 fingers and makes the focusing area smaller but has the disadvantage of placing hands at different levels and therefore let one slightly out of focus [12]. For patients without joint involvement, Inamadar's all-inclusive nail position seems ideal [13] (Fig. 15.5). Consistent positioning of the hand/foot between the two measurements is a requirement for future comparisons.

15.4.2 Hand Location: Backdrop

Backdrops are essential in good photography. They must be used to:

- Unify background, avoiding distracting and non-related images on the background.
- Facilitate standardization.
- Avoid "forcing" the lens (set in macro) to select between focusing the background or the subject. Black facilitates placing two images taken at different points in time.
- Green, light blue, black, and white color backdrops are used. The actual tendency is to use black backdrops. They generate better contrast and facilitate comparing clinical images taking at different times. In PowerPoint presentations (PPT), black background images blend nicely with a standard black background provided by PPT. Black absorbs excess light and does not reflects it.
- Light blue is best for darker skin types.
- Position of the subject (nails) in relation to the backdrop is also relevant. If in need to obviate a physical backdrop, simply separate the hands or feet from the background. The short depth of field of the macro lens combined with the precisely targeted illumination of the object by the TTL flash will artificially create a black background with a highly contrasted image [14]. Insufficient distance will record information on the background itself, giving a finally undesired effect. Black backgrounds (cotton or velour) will reduce shadows. There is however inconvenience of maintaining the hand or foot steady for the picture. In macro photography, tremors result in photos out of focus. Hands can simply be placed on top of a table over a colored backdrop (Fig. 15.6).

Fig. 15.5 All nails are included in one single frame; some patients might find it difficult or even not possible to place their fingers in this position

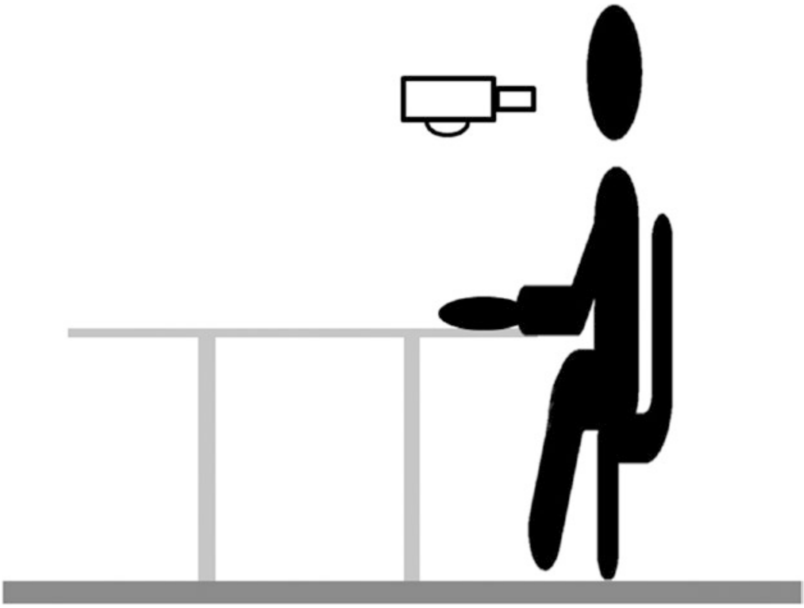

Fig. 15.6 Suggested patient–photographer position for hand nail photography

Kaliyadan et al. [4] suggest resting the fingers on a tripod, obtaining good results with distances shorter than 1 m with a 100-mm macro lens zoomed out with the flash on. For feet, the task is simplified because the patient can lie down or sit with the legs stretched on a bed while the backdrop is placed 1 m away. A rod covered with black paper can serve as a good backdrop as well as grip to place all eight fingernails in case a horizontal angle is preferred for photography (Fig. 15.7). Sometimes surface changes, e.g., nail pits, need to be highlighted for better contrast. In such cases, gentle rubbing with a carbon paper followed by wiping with a tissue will lead to deposition of carbon particles in the nail pits, leading to better demarcation of the nail pits.

Fig. 15.7 Grasping a rod can be helpful to position fingers

Feet position is much simpler (Fig. 15.8). With the patient lying down, the backdrop can be placed 1 m away, and the photograph is taken placing the camera close to the patient's knees (Fig. 15.9a) or having the patient sit bending his/her knees (Fig. 15.9b).

The use of scialytic lights—that disperse or dispel shadows—provides very high-intensity illumination which results in more contrasted pictures. Ideally, use of central single-point mode is to adjust the exposure and autofocus in the center of the operating scene [15]. For those that can operate counting with a professional photographer on site, focal length from 80 to 100 mm allows for a 70–80 cm distance from the operative field.

15.5 Cross-Polarizing Photography [3]

There are new cameras that come with a cross-polarized filter kit [16]. In reflection mode (Reflection mode is standard flash pho-

Fig. 15.8 Feet position for nail photography

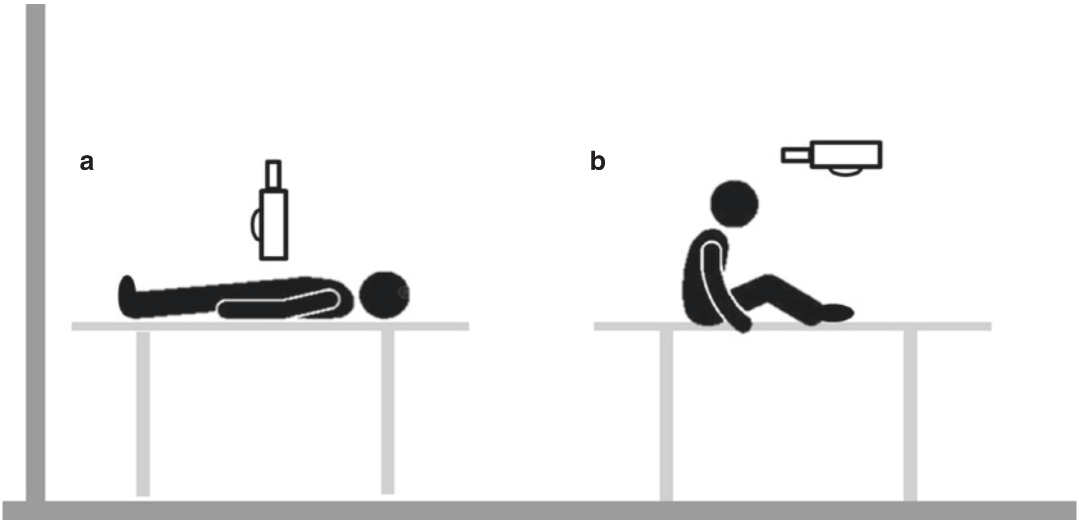

Fig. 15.9 Suggested patient–photographer position (shown as the camera icon) for feet nail photography. On the left side (**a**) with the patient lying down ; on the right side (**b**), with the patient sitting on the bed and bending her/his knees

tography where the camera captures light reflected from the subject) a cross-polarized image allows you to see through the nail plate and evaluate the skin beneath it (nail bed), which is where nail infections develop. In the transmission mode, a light source illuminates the finger(s) from underneath, and an image of the light transmitted through the finger and nail is captured from above. In the second mode, a red color light source is preferable since it will undergo negligible tissue absorption and have higher transmission compared to other colors.

15.6 Photographic Measuring Scale

Digital rules (DR) provide a neat, more precise, and professional way to measure photograph lesions. Stickers should be avoided as they look untidy, they can be difficult to place in the correct area and uncomfortable to remove. DR avoids contacting the patient. The digital rulers are dragged onto our image from a layer in a ready-made psd file, of which a number of sizes are available in the magnification ratios commonly used for close-up photography of lesions [17].

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Special Considerations: Hair Photography

16

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Contents

16.1 Introduction

Photography today is a well-established tool for imaging scalp and hair conditions. It is especially useful in assessing progress or response to treatments for sun-damaged skin or alopecias [1] as well as for single lesion documentation. Correct hair imaging is fundamental to support efficacy of a treatment. Taking photographs of the scalp and hair disorders has its challenges being positioning and lighting the most difficult ones to deal with. Even slight changes in any of these two parameters can make comparison impossible. For most scalp and hair conditions, the same general rules of medical photography apply.

Photographs of hair disorders often require close-up or macro modes. A backdrop is needed to standardize the image, and maintaining the same distance for sequential imaging is a requirement. Scalp erythema, scales, and lesions in general (nevi, seborrheic or actinic keratosis, malignant or benign tumors in general) are difficult to visualize and photograph in hairy scalps. Dermoscopic images taken with a shallow DoF (depth of field) might show either the hair or skin out of focus. In general, photographing skin conditions placed under hairy lesions is challenging and can result in the most difficult conditions to diagnose in teledermatology [2].

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16.2 Preparing the Patient

In hair documentation the patient needs to come to the photographic sessions with a clean and dry hair. If documentation is for monitoring the subtle changes caused by topical or oral alopecia treatments, then the hairstyle should be maintained during the entire period. It is important the patient maintains the same hair color and combing style. It has to be clean as oily hair will increase shining; wet hair looks different than the dry one. For curly hair it is best if it's fixed and dried before coming to the session as wet curly hair looks quite different than the dry one and in addition it is difficult to comb at the moment of the photographing session. Hair clips help in keeping the hair into place, especially when photographing the vertex; clips are also useful when trying to move aside side covering alopecia areata plaque.

Spot baldness or hairless scalp should be cleaned from sun protecting creams, oil, sweat, or any residue of dust or foreign substances. As in conventional medical photography, remove distractions (glasses, diadems, jewelry, or cloths). Backdrops should not be similar to the hear color. For dark hair, choose green, blue, or white. For light color, gray, or white hair, black color will do.

16.3 Position

There are some standard positions suggested for imaging the head. When photographing an isolated lesion of the scalp (for instance, a tumor before surgery or a pigmented lesion prior removal), the position is important but not crucial. The same general rules of medical photography apply: correct light, backdrop, depth of field, and white balance. Instead, special care should be taken in conditions requiring serial images as in monitoring treatment for field cancerization of the scalp or treatment response for different types of alopecia, just to mention two common conditions where serial head and hair photography is relevant. Patient positioning becomes crucial and extremely difficult as the neck's rotation gives infinite possibilities for placing the head (Fig. 16.1).

Since the head is convex, light changes in position can distort the shape and even hide a lesion. For alopecia, slight changes of position can put certain areas more in evidence than in the previous photograph. This can result in perceiving improvement or worsening when there has actually been none. For example, if a vertex photograph showing the hairy occipital area and a bald vertex of a patient is compared to a second photograph (taken to evidence changes from a topical treatment) having the head slightly tilted front, part of the baldness will be hidden, given the false impression of improvement.

Figure 16.1 shows an 86-year-old patient with frontal fibrosing alopecia and an X drawn on her left front side. Asking her to repeat the same position over time puts into evidence how difficult it is to place one's head in the exact position, causing distortions on the X.

A simple rotation in the transversal plane can be corrected in post-processing, while tilting the head on the sides or front to back changes the perspective and cannot be fixed in post-processing (Fig. 16.2).

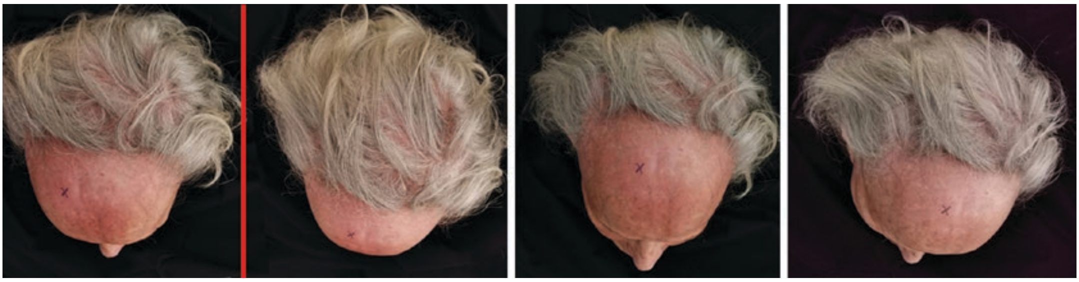

Fig. 16.1 The first scalp image is taken by marking an X on the right side of the front. The following three positions are some of the infinite possible variations caused by misplacing the head

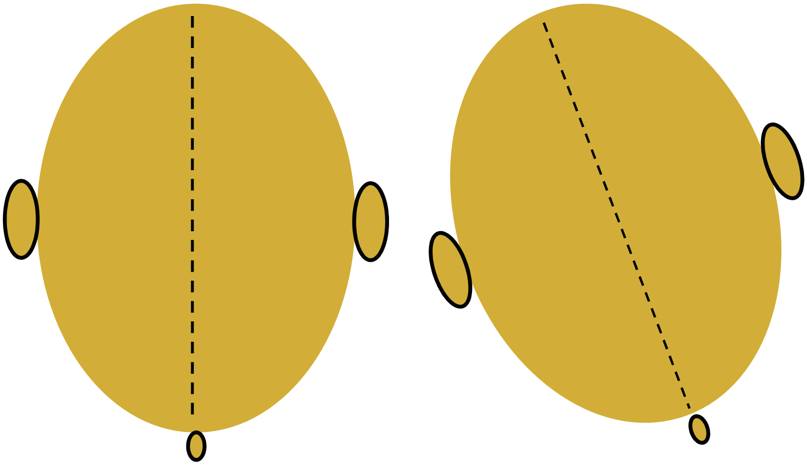

Fig. 16.2 This is a change in the same transversal plane. Position of the second image can be readjusted by simple rotation in post-processing

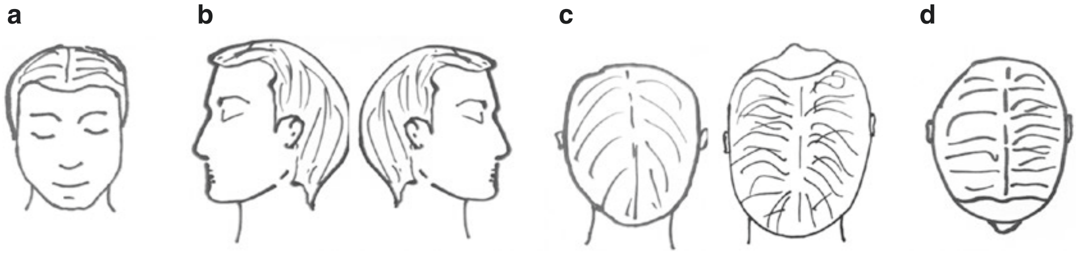

Fig. 16.3 Standard views for hair loss monitoring: (**a**) frontal, (**b**) temporal views (right and left), (**c**) top scalp, and (**d**) vertex

One solution for this common positioning problem is 3D photography as the "avatar" can be moved and set in comparable positions. Unfortunately, some of the systems available today for 3D imaging do not recognize hair. They can only be used for hairless scalp areas.

The standard views for hair studies are frontal and temporal views (right and left), top scalp (with hair center parted), and vertex (hair combed out like the spokes of a wheel) (Fig. 16.3).

Getting the patient into the exact position can be mechanically achieved by using a stereotaxic device which uses a set of three coordinates to maintain the head in a fixed position. The camera is mounted on a rotating arm which can move around the patient's head. Flashes are placed on the sides for a balanced illumination. Such systems are commercially available (Canfield®, TrichoScience Pro [3]) (Fig. 16.4).

16.4 Lighting

Lighting is very difficult to control when built-in flashes are used. Inevitably, a central washing off ("whitening") effect will be evident, light glares from the shiny surface of the bald scalp (Fig. 16.5). This will ruin the image not only because it adds an undesired element but also because it hides any potential lesion underneath. A flash diffuser helps reduce this undesirable effect. Cameras also have an intensity control over flash which can be used to reduce its intensity. Distance is also relevant: the closer we are from the patient, the more intense will be this flashlight effect. It is preferable to zoom in from a distance. Overexposure will always result in detail loss. Underexposure can instead give the perception of having more hair.

Fig. 16.4 Stereotactic system for hair photography by Canfield

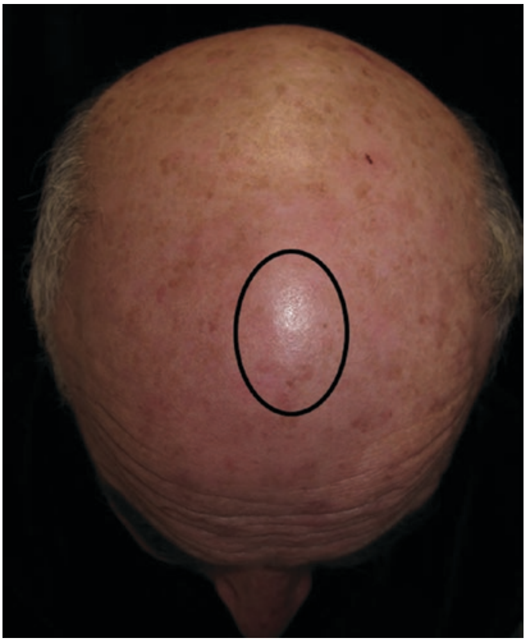

Fig. 16.5 Whitening (marked with oval) caused by built-in flash

The ideal light has to come from the sides. Therefore, use monolights with diffuser placed on the sides or a "twin-flash" system. This will enhance the perception of depth. Texture visualization will improve as well [4].

16.5 Focusing

To standardize the distance, the field of interest is selected and then manually focused. As mentioned in the chapter on Standardization (Chap. 14), the magnification ratio in digital photography refers to the ratio that exists between the size of the image projected on the sensor and the real size of the object size. In a full-frame DSRL, an area approximately the size of an adult head will require a magnification ratio of 1:10. This is also called body focusing, and consistency in the magnification ratio will result in comparable before and after images. The aperture is usually F11 and F16, to guarantee a deep DoF. Serial imaging will also benefit from overlaying the new image over the new one (as done in apps like MySkinSelfie, among others). This superimposition helps orienting the patient into the exact position.

16.6 Conclusion

Photography is an important tool in the management of patients with hair and scalp conditions. A basic photographic protocol will result in reproducible high-quality images that can be later be part of the medical record of the patient, for second opinion and, most important of all, for comparison over time. Qualitative and quantitative analysis will only be possible if we take excellent and comparable images right from the beginning of a series of images.

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Digital Dermoscopy Images

17

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Contents

17.1 Introduction

Dermoscope is a high-quality magnifying lens with a powerful lighting system that allows inspection of microstructures of the epidermis, dermoepidermal junction, and papillary dermis not visible to the naked eye.

Digital dermoscopy (videodermoscopy) consists in storing dermoscopic images captured by hand-held devices or by electronic dermoscopes.

17.2 Different Types of Light Used in Dermoscopy

A dermoscope is formed by a light source and a magnifying optic (usually with a tenfold

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magnification). There are three different types of dermoscope:

- Non-polarized light, contact dermoscope
- Polarized light, contact dermoscope
- Polarized light, non-contact dermoscope

Non-polarized light, contact dermoscopes require a liquid interface between the scope and the skin to reduce the amount of light reflected, refracted, and diffracted by the stratum corneum.

Immersion liquids that can be used include water, mineral oil, alcohol, and gel. According to some authors, 70% ethanol is the best immersion liquid for the greater reduction of air bubbles [1]. In the regions close to eyes or mucosa, the use of alcohol is discouraged because it might cause a burning sensation. For this reason, a water-soluble gel, like ultrasound gel, is preferred. Another indication for gels is dermoscopy of nails because they flow off upon the smooth, convex surface of the nails less than liquids [2].

Polarized light dermoscopes, recently introduced, allow visualization of the deep skin structures without a liquid interface. Shiny white streaks (crystalline or chrysalis structures), high specific for melanoma, are visible only with polarized light [3].

Furthermore, **polarized light, non-contact dermoscopy** allows a better visibility of scales and vessels because it does not require a liquid interface and does not apply a pressure on the skin. However, some superficial findings, such as comedo-like structures, are better seen with non-polarized light devices (Table 17.1).

Table 17.1 Different types of dermoscope and their uses

Non polarized light, contact dermoscope	Superficial findings, such as comedo-like structures, are better seen with non-polarized light devices
Polarized light, contact dermoscope	Allows visualization of shiny white streaks (crystalline or chrysalis structures), highly specific for melanoma
Polarized light, non-contact dermoscope	Allows a better visualization of scales and vessels

Table 17.2 Equipment for dermatological images

Smartphones/ tablets	Capture dermoscopic photos thanks to adaptors for dermoscopes. Easy to use. Low cost. Quite acceptable quality of images
Point-and-shoot cameras	Some devices have dermoscope-compatible adaptors, while others are designed for both clinical and dermoscopic images
Interchangeable lens system cameras	Need an adaptor to mate a dermoscope. Excellent image quality. Expensive

17.3 Equipment and Devices for Dermatological Images

Clinical photography is an essential tool for any medical speciality, especially for dermatology. In the last 10 years, the improvement of digital photography has reached extremely fine resolution (compared with traditional photography), becoming the first choice in the clinical practice [4, 5]. Nowadays, there is a great variety of devices available to capture dermatological images, including smartphone/tablet attachments, compact digital cameras ("'point and shoot" cameras), and interchangeable lens system cameras (Table 17.2) [6, 7].

Compact digital cameras are equipped with an automatic mode and a number of scene modes to adapt photos to different situations, without changing camera's exposure setting.

Interchangeable lens system cameras, instead, can be used in full manual, automatic or semi-automatic modes.

17.4 Parameters Affecting Photo Quality

Some device parameters affect the quality of images and should be considered by dermatologists (Table 17.3).

The question of what is the ideal resolution for dermatological photography has been an often-discussed topic. The amount of details that a camera can capture is called resolution and is measured in pixels. The more pixels a camera has, the more detail it can capture. Nowadays, all new

Table 17.3 Device parameters affecting photo quality

Resolution	The number of camera's pixel
Low-light capability	The ability to take good pictures with low light
Dynamic range	The spectrum of colors captured, from the brightest to darkest ones
Camera lens quality	Greater clarity of focus, details and depth of field depend from the quality of lens
In-camera processing	The ability of manipulating images, applying filter, changing color, contrast, etc.
Color fidelity	The accuracy to reproduce colors
Post-processing	The manipulation of images with software after they moved off the device into a computer

cameras available in the market for dermatological use have a minimum resolution of 3 megapixels.

17.5 Types of Dermatological Photos

For an accurate documentation of a skin disease, it is important to take three types of photos (contextual photos, macro-photos and micro-photos) (Table 17.4).

Before taking a picture of a patient, it is necessary to obtain documented informed consent, to ensure adequate lighting and to use a monochromatic background, avoiding unnecessary distracting colors or objects [8]. If the available ambient light is insufficient, the operator should use an electronic flash. Conversely, using a flash, or shooting at a 90° angle to the skin surface should be avoided for minimizing the reflection.

Despite the widespread use of photography, technical guidelines for acquisition and storage of images do not exist.

For routine practice, the following tips could be useful:

- Try to take photographs in the same settings regarding patient position, background, lighting, and camera settings
- Use auto-focus as often as possible
- Select the "macro" mode for close-up images

During micro-photos acquisition, air bubbles can be introduced into the immersion fluids, distorting the image quality. The use of gel as immersion liquids and an adequate pressure when camera is applied minimize the bubbles. In contrast, bubbles are relatively frequent with oil use.

Table 17.4 Types of dermatological photos

Contextual photos	Provide a general overview of the dermatosis in relation to the anatomical site affected, giving information about the location, size of the lesion, and possible deformity or loss of function
Macro-photos	Are close-up images of the lesion characterized by a scale of 1:1 or 1:2. The surrounding anatomic structures are not visible
Micro-photos	Correspond to dermoscopic images, captured with a 10–15× magnification

17.6 Digital Dermoscopy: The Uses of Dermoscopic Images for Monitorization

Digital photography offers particular advantages in image archiving and space storage.

Digital dermoscopy (videodermoscopy) consists in storing the dermoscopic images captured by hand-held devices or by electronic dermoscopes with a computer link. These latter devices transfer automatically the images into a database. Digital dermoscopy is useful for storing the images of a lesion before the surgical excision and for monitoring a suspicious lesion (sequential digital dermoscopy).

Sequential digital dermoscopy is an examination method used for recognition of early melanomas in patients with multiple moles. In fact, about 10% of melanomas do not show at the baseline examination clear-cut clinical and dermoscopic features of malignancy [9]. Sequential digital dermoscopy consists in the storage of clinical and dermoscopic images of pigmented lesions and in their comparison after an interval of time. In case of asymmetrical changes, frequently associated with suspicious lesions, a biopsy of the lesion should be mandatory. The interval between the examinations should be adapted to the individual risk profile, but usually it is about 3–6 months.

Despite the worldwide diffusion of digital dermoscopy, actually there are no standards for acquisition, storage, and display of the images, and this is a limitation for comparison between dermatological photos.

Over the last years, several computer systems of automated image analysis have developed for the screening of melanoma [10]. Mole-analyzers use an algorithm to calculate an overall severity score based on the evaluation of variables correlated with melanoma. Despite the great media resonance of these systems, a meta-analysis demonstrated that their sensibility was not statistically superior to that of clinicians [11].

In particular, these devices have not a sufficient discriminatory power to distinguish between non-pigmented benign lesions, such as seborrheic keratosis, and melanoma.

17.7 The Storage of Dermoscopic Images and Follow-Up

Today, several systems of digital photography acquisition are available on the market; they support the clinical evaluation for skin cancer screening, helping the specialists to early detect dermoscopical changes in the skin and avoiding unnecessary excisions. **Digital dermoscopy follow-up (DDFU)** is essential for high-risk patients (i.e., people with a familial or personal history of melanoma, large number of naevi, a genetic predisposition to melanoma) [12]. DDFU is not appropriate for nodular lesions, with signs of regression and/or others criteria of clear-cut melanoma. Instead, a meta-analysis has shown the advantages of DDFU in the detection of thin melanoma with a low rate of avoidable excisions [13].

The computer-aided dermoscopy system fulfills all requirements both for a brilliant image acquisition and storage through the connection to a computer.

All cameras use polarized light, so they do not require any immersion fluid for the epiluminescence analysis; they are equipped with a dual circular LED illuminator, that acquires dermoscopic and clinical images with fine details and color fidelity in high magnification (Figs. 17.1 and 17.2). These devices have a fully digital system of data transfer via HDMI and a dual LCD monitor. Mole analyzer software digitally removes hairs and bubbles, performs segmentation (identification of lesion borders), determines border regularity, and measures geometric parameters. Analyzed images can be stored and compared according to the time of follow-up established by the dermatologist (Figs. 17.3 and 17.4).

Two strategies of DDFU have been established for high risk patient monitoring: long interval follow-up strategy based on examinations at 6–12 months [14–16] and short interval follow-up strategy, with examination at 2–3 months [17]. The best strategy is reached by combining both methods with the first follow-up after 2–3 months and further examination at 6–12 months. Despite all the advantages, the use of DD is still reduced in some countries (e.g., only 8% of private practice dermatologists in France have access to a digital dermoscope) [18].

Fig. 17.1 An example of camera for macro and micro-photos

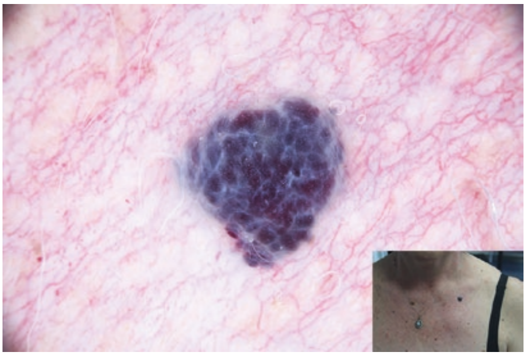

Fig. 17.2 Clinical and dermoscopic image of hemangioma acquired by videodermoscopic system

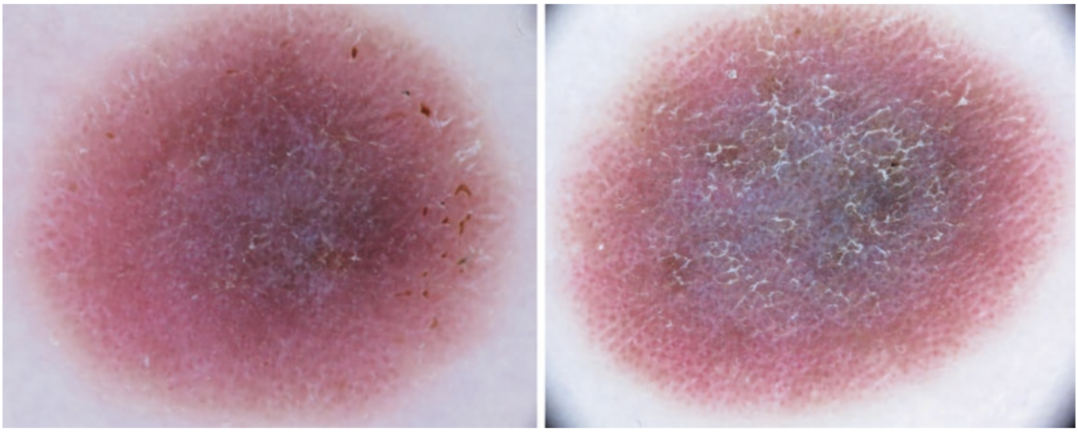

Fig. 17.3 Three-month follow-up of a Spitz nevus

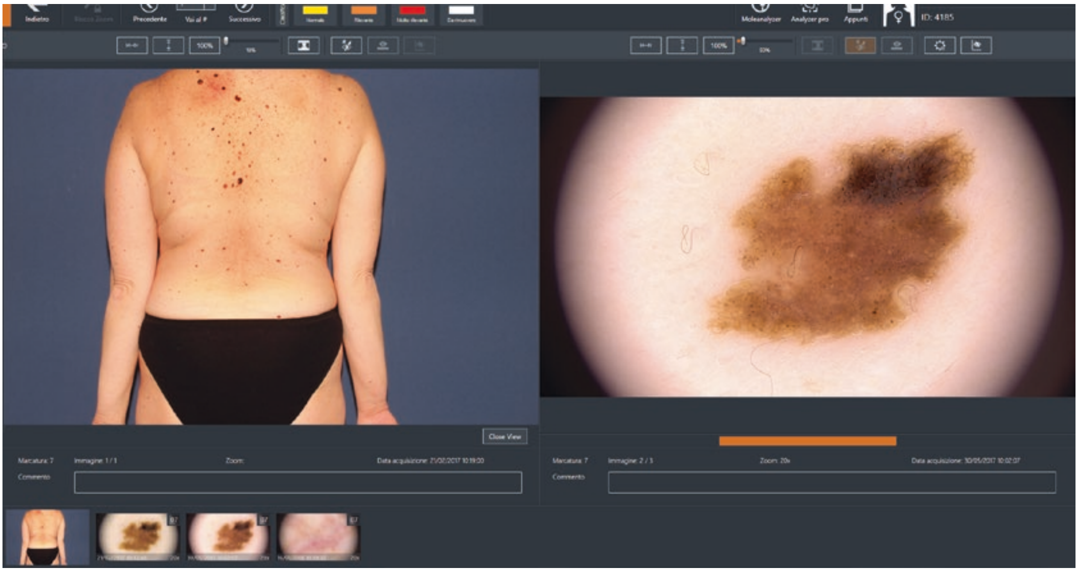

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Fig. 17.4 Example of digital acquisition

A recent review of technology standards for routine camera-acquired skin-disease images concluded that dermatological imaging is evolving without defined standards. The absence of standards is a major limitation for integration of dermatologic images across systems that support diagnosis, documentation, and research [19].

For example, type of light source (polarized or non-polarized light) is indeed delegated to the user and depends on the lesion (e.g., seborrheic keratosis is better evaluated with non-polarized light).

Another important concept raised from the consensus is the implementation of a physical scale for close-up of dermoscopic images: current imaging technologies have indeed the capability of inputting the size of the lesion without the need for a physical scale [19].

Moreover the use of a neutral gray background, in addition to the proposed blue or black color, which might enable better imaging of dark skinned patients, may need to be reevaluated [19].

It may also be useful to consider procedures to assure that the camera is perpendicular to the skin area and to correct for potential image distortion secondary to camera orientation [19].

17.8 Educational Uses of Dermoscopic Images

Among the image collection programs, the system **VisualDx** deserves a particular mention. VisualDx was first developed by Logical Images for the diagnosis of pediatric, adult, and geriatric dermatologic conditions. Dermatologic diseases are notoriously difficult for non-dermatologists to diagnose. Federman et al. found a significant difference in the diagnostic skills of dermatologists (93% correct), compared to primary care physicians (52% correct), when viewing images of the most common skin diseases [20]. VisualDx was designed to meet the needs of users who may not see dermatological manifestations everyday: primary care physicians, emergency room physicians, dentists, infectious diseases specialists, and public health workers. The first step is to indicate the type of lesion (e.g., adult rash) and then the distribution and other findings or symptoms. Consequently, VisualDx displays images of potential diagnoses ranked by the number of matched criteria. The images and monograph for a given diagnosis can be accessed from the results screen. VisualDx provides a unique graphical interface, made of a wide selection of high-quality images, to support diagnostic process of beginners and dermatologists.

17.9 Teledermatology and Teledermoscopy: Conclusion and Future Considerations

Teledermatology is a useful alternative where specialized dermatological assistance is not available; it's used by healthcare professionals for triage, consultation with patients or colleagues in medically undersupplied locations and follow-up of patients with chronic disease [21].

Teledermoscopy consists of dermoscopic images in teleconsultation taken with a digital dermatoscope or a standard digital camera with a dermoscopic attachment.

Teledermatology and teledermoscopy have many benefits (improve quality of care, avoid unnecessary referrals and reduce costs) but also some barriers (legal issues, security and absence of skin palpation).

In conclusion, teledermatology is an efficient healthcare service but face-to-face care remains the gold standard for diagnosis.

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18

Total Body Photography as an Aid for the Early Detection of Skin Cancer

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Contents

18.1 Introduction

Melanoma incidence is on the rise and despite growing knowledge regarding the primary morphology of melanoma, deaths due to advanced disease, resulting from delays in early diagnosis,

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All the authors contributed to acquisition, analysis, and interpretation of data; drafting and revising the article; and final approval of the version to be published.

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continues to claim the lives of evermore individuals with each passing year [1–5]. While we have made great strides in treating patients with advanced melanoma, thereby extending their life expectancy, the most effective intervention to avoid melanoma mortality is early detection, followed by surgical excision [6, 7]. Periodic skin cancer surveillance examinations, especially in individuals at increased risk for developing melanoma, has shown to be an effective method for early detection [6, 8]. However, many individuals at high risk for melanoma have a plethora of nevi, many of which display morphologic features overlapping with those manifested in early melanomas (Figs. 18.1 and 18.2). To complicate matters, melanomas commonly fail to manifest clinically recognizable ABCD features, fail to be outlier (ugly duckling) lesions, and fail to display any dermoscopic melanoma specific features; thus the challenge is to select out the early melanomas from among an ocean of nevi (Fig. 18.3) [9, 10]. Toward this end some have advocated the systematic excision of all melanocytic lesions in high-risk patients [11, 12]. The underlying rational being that this will result in the removal of any inconspicuous melanomas and also the removal of all potential precursor lesions. However, it should be stressed that while small subsets of genetically prone patients with a melanoma penetrance reaching over 90% do exist, most high-risk patients will never develop a melanoma in their lifetime (cumulative 10-year risk of around 7.2–12%) [13–19]. Although the actual risk of developing melanoma in high risk patients is dependent on many factors such as geographic location of residence, number of nevi, age, degree

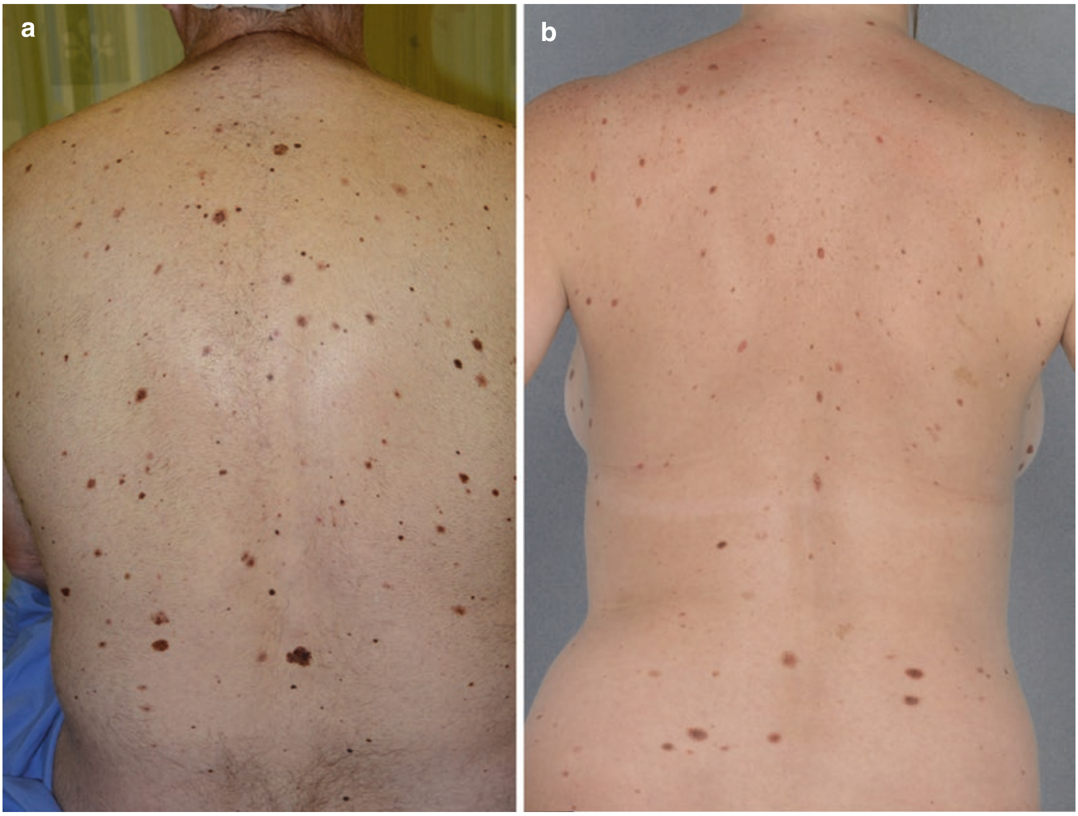

Fig. 18.1 Patients with multiple nevi displaying increased variability in size, shape, and color. This phenotype has been referred to as atypical mole syndrome (AMS). (**a**) A male in his 50s with a high-risk phenotype. Note the high number of nevi and how the moles differ in size and shape. (**b**) A female in her 40s with a high-risk phenotype with fair skin type and multiple nevi of differing sizes

Fig. 18.2 A male in his 30s with multiple nevi. Note that he has numerous scars (asterisks, approximately 8) resulting from excision of melanocytic lesions. All biopsies were reported as dysplastic nevi, and no melanomas have been diagnosed to date. The excision of multiple nevi is not uncommon in patients with the AMS phenotype

and severity of sun exposure, skin type and degree of freckling, even those deemed to be at highest risk based on the aforementioned factors have a lifetime risk of <20% for developing melanoma [20]. Furthermore, most nevi will never progress to melanoma, and the prophylactic excision of all nevi cannot eliminate the risk for developing melanoma since overall 70% of melanomas occur de novo and only 30% of melanomas arise in association with a precursor nevus. It is also important to underscore that evaluation of the nevus component of the nevus-associated-melanomas reveals that frequently the nevus is a non-dysplastic nevus (50%) and the pathology often displays a pattern of a superficial congenital nevus [21–23]. Even when specifically looking only at patients with hundreds of nevi, most will never develop melanoma [17–19]. In this particular subgroup (patients with the atypical mole syndrome), however, melanomas tend to develop more often in association with a preexisting nevus. Particularly, in patients with the atypical mole syndrome, 30–60% of melanomas are "nevus-associated melanomas," most commonly of the dysplastic nevus subtype (up to 97%) [14, 17–19]. It is also important to bear in mind that the concept of pro-

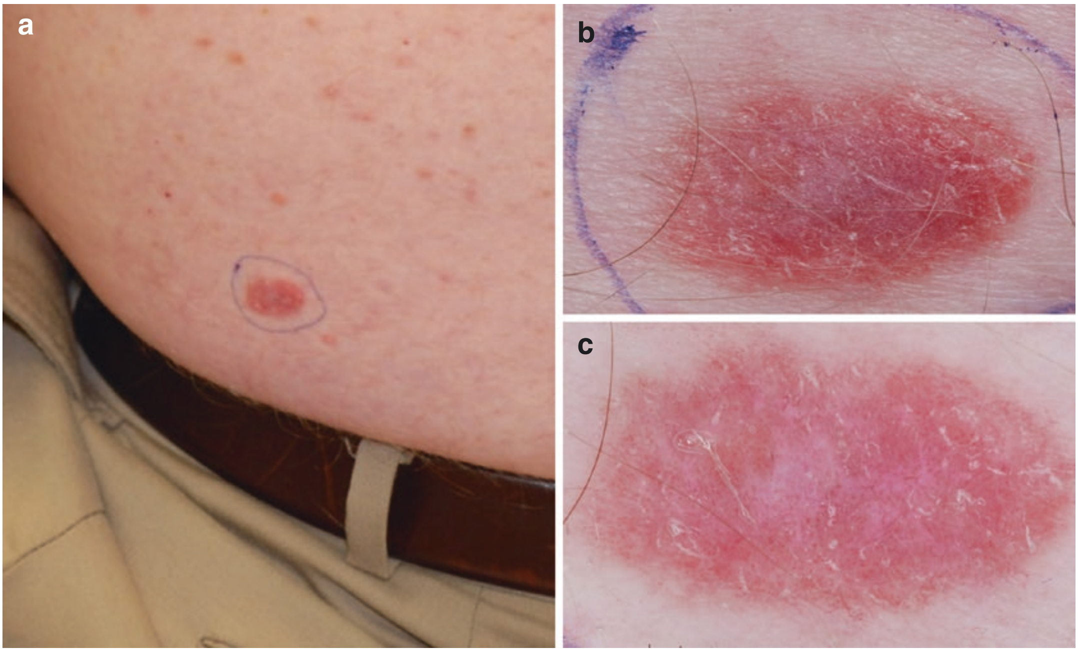

Fig. 18.3 Some melanomas lack ABCD criteria. (**a**) A male in his 60s was referred for evaluation of this solitary lesion on his left abdomen. (**b**) The lesion lacked ABCD melanoma criteria. (**c**) On dermoscopy, it showed polymorphous vessels. A biopsy was performed and revealed melanoma, superficial spreading type, 0.5 mm in thickness

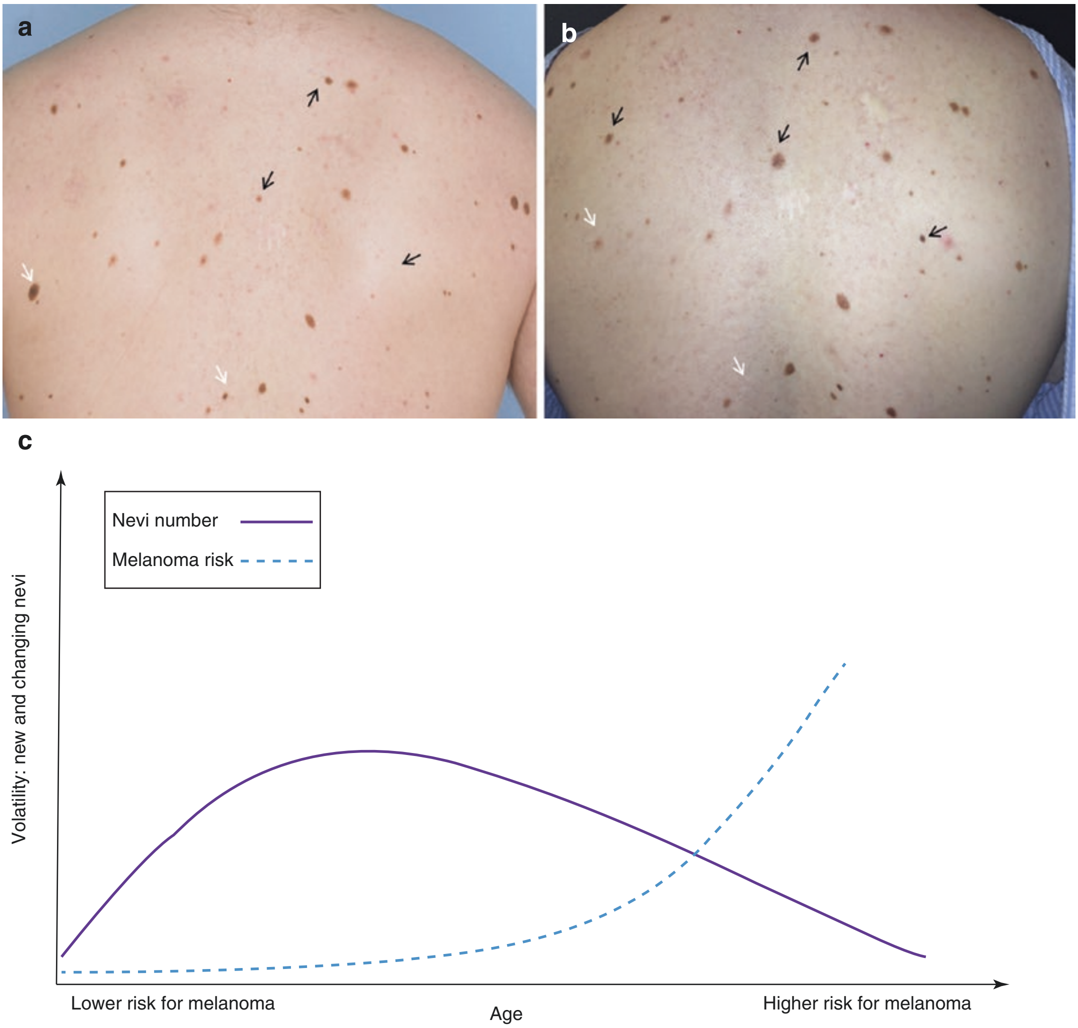

Fig. 18.4 Nevi are dynamic lesions. Left panel (**a**) represents the baseline image and the right panel (**b**) is an image obtained 3-year later. Notice that some new nevi have developed, some nevi have grown (black arrows), and others have disappeared (white arrows). (**c**) Graph highlighting that the risk for melanoma is low during adolescence, and early adulthood but nevus volatility is high. In contrast, while nevus volatility decreases with age, the risk for melanoma increases with age

phylactic removal of all nevi would continuously require the excision of all new nevi developing throughout the lifetime of the individual (Fig. 18.4) [24]. Since most nevi in high-risk patients do not change, and in light of the evidence that surveillance with the use of total body photography (TBP) and dermoscopy is associated with finding early melanomas, prophylactic excision of all nevi in these patients, with its associated cost, morbidity, and cosmetic end results, is a tremendously (and unjustified) high price to pay [19, 25–27]. Fortunately, most nevi in adulthood are in a state of clinical senescence and do not change over time (Fig. 18.5) [26, 28]. In contrast, melanomas are dynamic lesions that will continuously change over the course of time (Fig. 18.6) [29]. This natural behavior of nevi versus melanoma serves as the underpinning for the use of baseline imaging as an aid for melanoma detection. The ability to compare the patients' nevi to a set of baseline images obtained at a prior point in time allows us to utilize the comparative recogni-

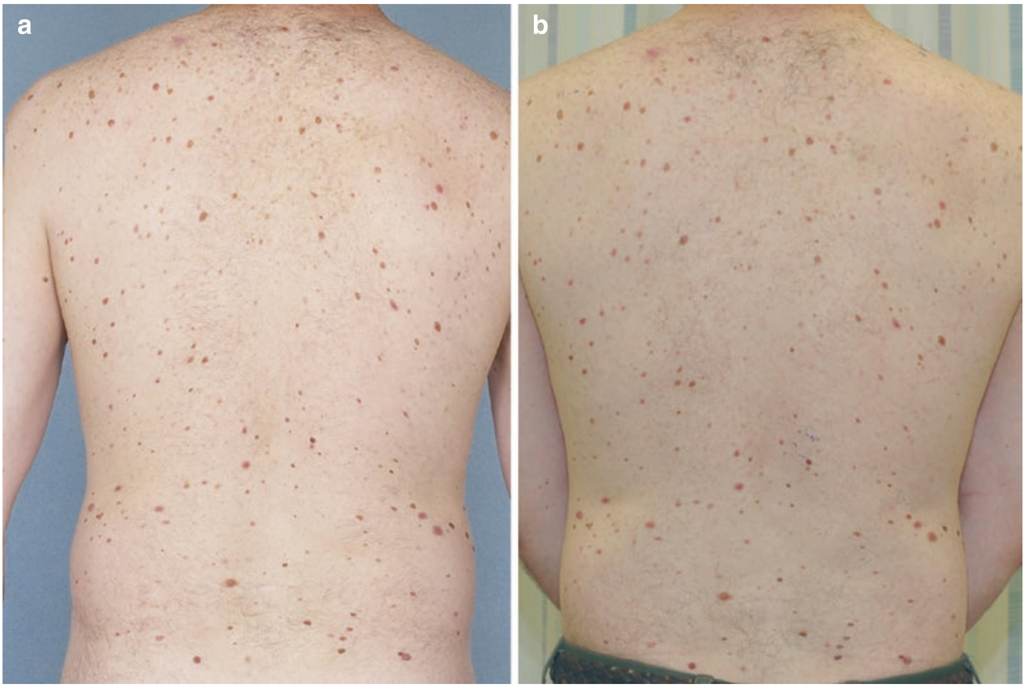

Fig. 18.5 A male in his 50s with atypical mole syndrome (AMS). Most senescent nevi remain stable and do not change. Left panel (**a**): total body photography of his back showing many atypical nevi. Right panel (**b**): photo of the back re-taken 6 years later. Comparing panel (**a**) and (**b**) shows that this patient's nevi have not changed

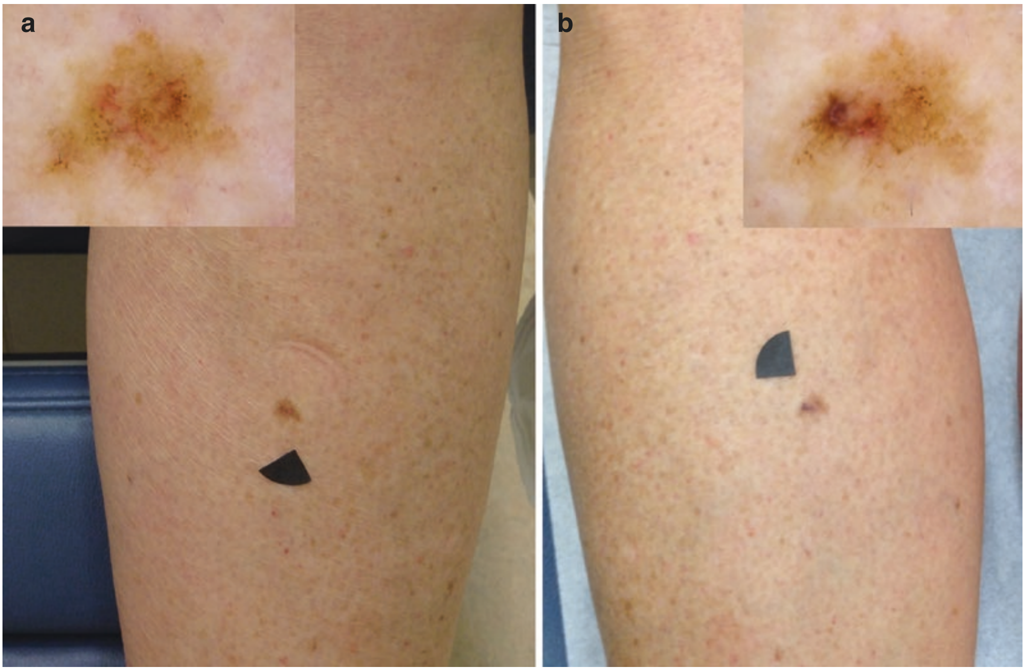

Fig. 18.6 A female in her 60s was being followed with total body photography. During one of her visits, an enlarging lesion was noted on her right leg. Comparing the lesion (Right panel **b**) with her baseline images (Left panel **a**) taken 1 year previously discloses a clear change in this lesion. Dermoscopy (inset) also revealed changes. The lesion was excised, pathology revealed a microinvasive 0.17 mm melanoma

tion process to identify new or subtly changing lesions that may be an early melanoma (Figs. 18.6 and 18.7) [30]. However, while change is a sensitive feature of melanoma, it is not highly specific [9, 31, 32]. Fortunately, we have the ability to utilize other tools and techniques such as dermoscopy, confocal microscopy, and short-term digital monitoring to evaluate these lesions and target for biopsy only lesions with features concerning for melanoma, thereby raising our specificity while still maintaining a high sensitivity [28, 33–35].

Over the past few decades, the imaging modalities of digital dermoscopy and TBP have played an ever-increasing role in the early detection of melanoma. Studies utilizing both TBP and dermoscopy (including dermoscopic digital monitoring) have shown that approximately 40% of melanomas detected in high-risk individuals are found solely due to changes noted on comparison to baseline images (Figs. 18.6 and 18.7) [17, 18]. Thus, despite the many technological advances aimed at evaluating individual lesions to differentiate nevi from melanoma, simple baseline TBP still plays an important role in the effort to find early melanoma while at the same time reducing the unnecessary removal of clinically and biologically benign lesions. This chapter will focus on the role of TBP as an aid for the early detection of melanoma.

18.2 What Is TBP and What Is the Rationale Behind TBP?

The history of TBP begins in 1988 with the pioneering work of Dr. Alfred W. Kopf [36]. He realized that clinicians struggle when examining high-risk melanoma patients since many of their nevi had morphologic features overlapping with melanoma (Fig. 18.1). He also realized the power

Fig. 18.7 A male in his 40s with the AMS was noted to have a new lesion on his leg. Left panel (**a**): Baseline total body photography sector of his leg. Right panel (**b**): 8 years after the baseline images were obtained, a new pigmented lesion appeared on his right calf. Dermoscopy revealed an atypical network with focal streaks (inset). Biopsy of this lesion revealed a melanoma in situ

of comparative recognition, which is the main principle governing the logic behind TBP. The usefulness of TBP to distinguish nevi from melanoma is based on the fact that despite being morphologically similar, melanomas and nevi are biologically different. Whereas there is a tendency to grow and change in the former, there is a propensity to remain stable or minimally change in the latter (Fig. 18.5). Thus, lesions confirmed, via comparison to baseline TBP, to be quiescent over time are deemed to be biologically indolent and those that reveal change are deemed concerning for melanoma [36]. Studies have also shown that use of TBP can potentially diagnose melanomas earlier at a more curable stage [16, 36, 37]. Nevertheless, TBP was initially criticized by many. Editorial quotes included: [38] "What is the purpose of all this? If a patient appears to my office with a dysplastic nevus, I will excise it. I am not going to photograph it to see if it changes"; [39] "It may not be practical for dermatologists in practice to obtain total-body photographs"; [40] "I am going to excise it […] I never watch and wait if I see something suspicious"; [39] and "When I see a new patient with a lot of suspicious nevi, I pick about four or five of the absolutely most suspicious lesions and remove them at that visit. I then schedule several follow-up visits and remove four or five more suspicious lesions in descending order" [39]. Clearly, times have changed, and the practice of monitoring lesions for change is a regular practice in almost all high-risk clinics around the world [41]. Improving our ability to find early melanomas while minimizing the removal of nevi is responsible for the acceptance of TBP in the management of high risk patients; technological advances have helped accelerate its use. In the 1980s, obtaining TBPs was a time-consuming endeavor; the images were acquired using analog cameras and the film had to be processed and then the images were either printed out on paper or projected on a rearview projector and patients were compared to the baseline images in real time. Today, TBP are acquired with digital cameras, and these images can immediately be projected on high-resolution computer screens (Fig. 18.8) [37, 42]. Other advances in technology that will likely continue to make it easier for clinicians to use TBP include 3-D TBP (Fig. 18.9) and computer-assisted detection of new and changing lesions (Fig. 18.10) [43].

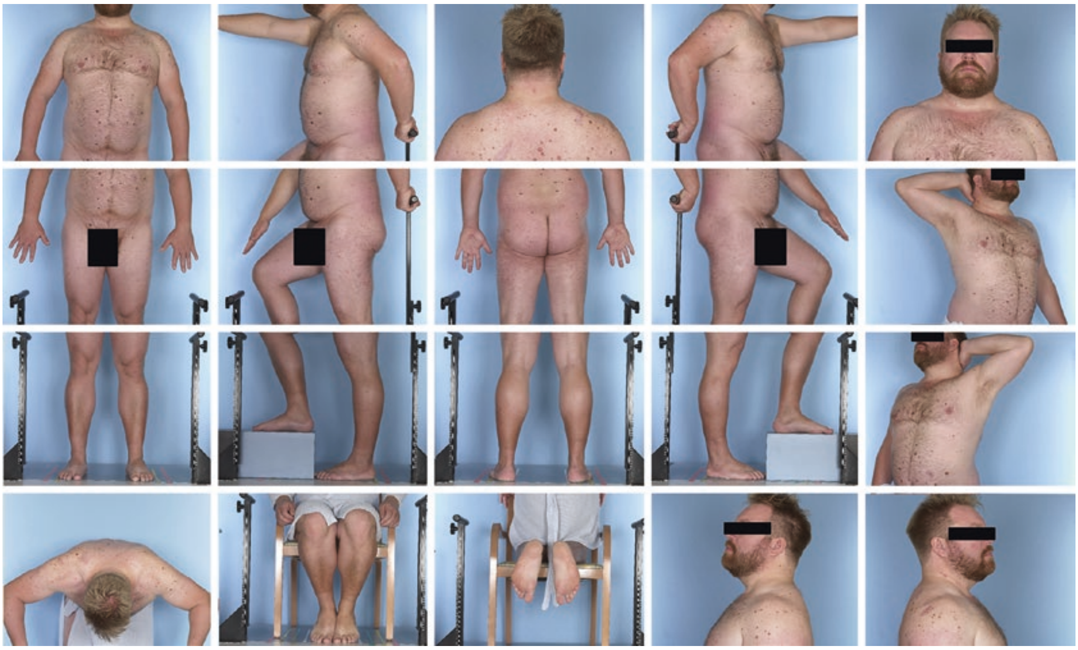

Fig. 18.8 Proposed standard poses (body sectors) for 2D total body photography according to Halpern et al. [42]

Fig. 18.9 Three-dimensional total body photography system. Patients stand inside the imaging booth and 92 cameras firing in unison acquire images of the entire skin surface. Computer software stitches these images together to create a 3D avatar of the patient. (Image courtesy of Canfield Scientific Inc., Parsippany, NJ, USA)

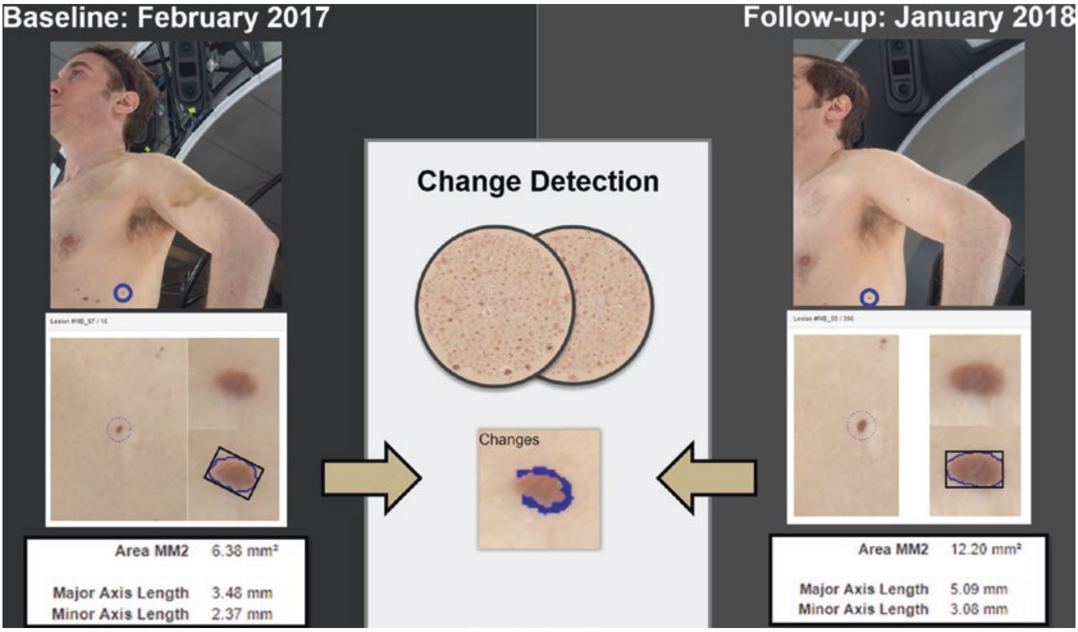

Fig. 18.10 Computer-assisted technology in the detection of new or changing lesions using 3D photography. In the left panel, the nevus had an area of 6.38 mm^2, after 1 year (right panel), the nevus had an area of 12.2 mm^2

Systems used to generate 3-D TBP utilize as many as 96 strategically placed cameras to capture 2-D images of the patient. Computer programs are then used to stitch together the individual 2-D images to create a 3-D avatar of the patient (Figs. 18.9, 18.10, and 18.11). The clinician or patient can rotate, zoom in and out, and position the avatar at any desired angle to facilitate direct comparison of the patient's lesions to the baseline 3-D images. This in turn enables and facilitates easy detection of new or changed lesions, including those located on curvatures and convexities of the body. Another development, which is being applied in 3-D TBP, is the use of polarized light [44]. The use of polarized light and cross-polarized filters helps eliminate specular reflectance produced by the reflection of light off the skin, which results in a macroscopic quasi-dermoscopic image of the skin (Fig. 18.11) [45]. Zooming in on the individual lesions present in a 3-D avatar captured with polarizers do in deed disclose more morphologic details (quasi-dermoscopy) then the same avatar captured without polarizers (Fig. 18.11); however, it remains to be determined whether the ability to visualize this added degree of morphologic detail on TBP will translate into easier and earlier detection of skin cancers. The aforementioned advantages of 3-D TBP do come at a price including the expense of the imaging unit, the need for a dedicated room with a large floor space given that the unit's footprint can be as large as 2.85 m × 3.45 m base and 2.70 m height (these dimensions are subject to

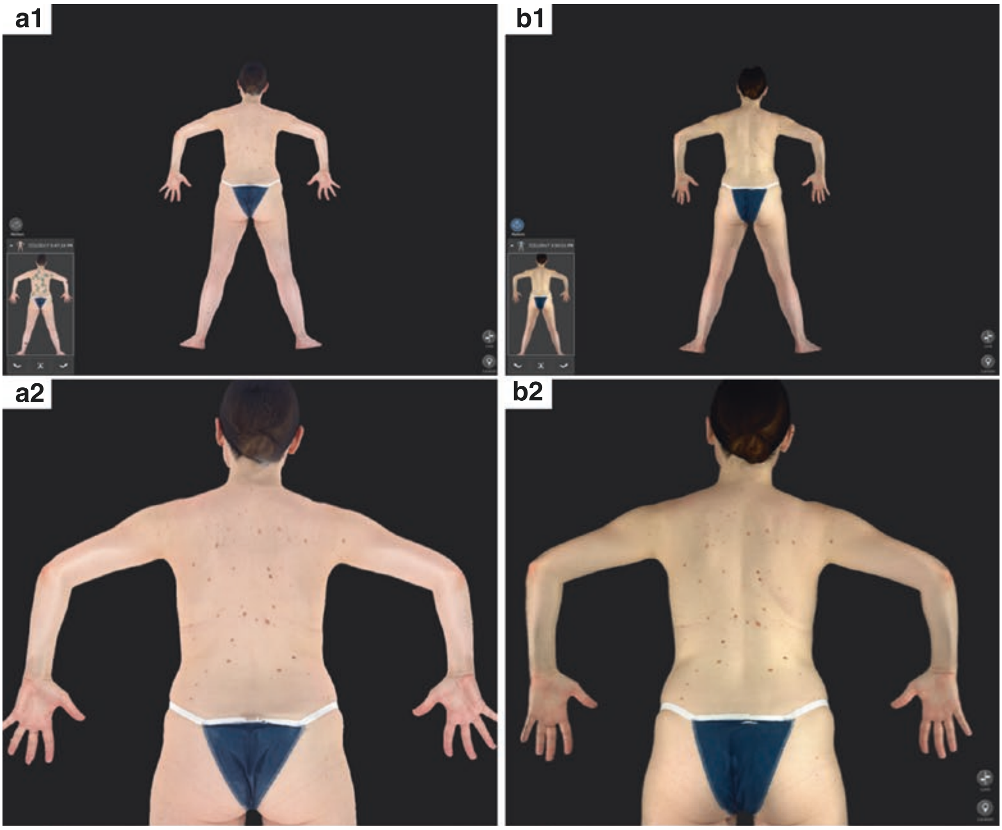

Fig. 18.11 Comparison of a 3-dimensional total body photography taken with non-polarized cameras (column **a**1–**4**) and with cross-polarized filters (columns **b**1–**4**). Figure (**a1**) is a screen capture from the 3-D avatar of a patient acquired without cross-polarizers. Figure (**b1**) is a screen capture from the 3-D avatar of the same patient acquired with cross-polarizers. Zooming in on one nevus on the back discloses that the cross-polarized image (**b4**) reveal more morphologic details (quasi-dermoscopy) as compared to the non-polarized images (**a4**)

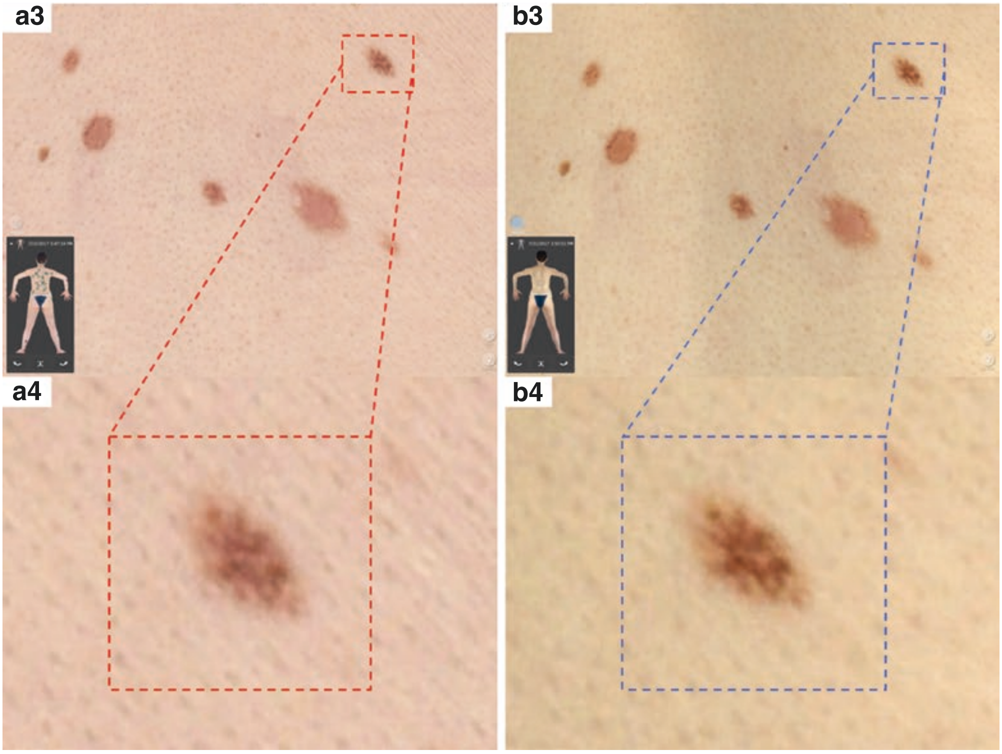

Fig. 18.11 (continued)

change), and the need for large data storage space since each avatar comprises at least 2 gigabytes of data. Finally, new ways of acquiring TBP images are still being developed such as the acquisition of images via small drones that create a map by flying around the patient. Surely we will see many developments in the way images are acquired in the foreseeable future.

18.2.1 Use and Beliefs of Physicians

The use of TBP has increased over time with only one academic center (AW Kopf at NYU) using TBP in 1988 to over 70% of academic centers in the US using TBP in 2010 [46]. A survey performed by Nehal et al. in 2002 showed that 63% of academic centers used TBP [47]. The latest US-based survey taken in 2010, indicated that 71.1% of academic centers reported using TBP, an 11.9% increase over the prior 10-year period [48]. The respondents were also asked to provide a score reflecting the importance of TBP in their practice. They provided a mean score of 6.9 on a scale from 1 to 10. Respondents indicated that the main reasons for use of TBP were to monitor patients with "many atypical nevi" (≥5), as well as to monitor patients with "many (>100) 'common' nevi." Despite increased uptake in academic centers, 67.4% of residents would still prefer additional TBP training [48]. This desire of residents to want more exposure to TBP is an indication that its use will likely continue to increase and that it will also permeate into non-academic clinics. While the above data is encouraging, the numbers likely overestimate the actual use of TBP in the community as the surveys were conducted in academic centers and the respondents were likely biased toward individuals with special interest in pigmented lesions [48, 49]. There is a worldwide paucity of information regarding TBP use in private practice/non-academic centers.

18.3 Benefits of TBP

Patients at high risk for melanoma often harbor many nevi, some of which may be clinically dysmorphic, leading to the challenge of distinguishing nevi from melanoma (Fig. 18.1). Some have argued in favor of gradually starting to remove “suspicious” lesions, or even removing all patients’ lesions [11, 39]. However, experienced clinicians caring for high-risk patients in pigmented lesion clinics have found that TBP augments their ability to detect early melanoma while reducing the number of nevi being excised [25]. Without the aid of TBP and dermoscopy, the number of nevi needed to excise (NNT: number needed to treat) to detect a melanoma in pigmented lesion clinics varies between 20 and 55 [6]. TBP has impacted NNT by (1) aiding dermatologists in detecting subtle changes and new lesions in high-risk patients [17–19, 31, 49–51]; (2) minimizing unnecessary biopsies [19, 25, 52, 53]; and (3) promoting self-skin examination by patients and reducing patient’s anxiety [54–58].

1. *Enhancing detection of subtle changes and new lesions in high-risk patients:* Change is a sensitive feature for melanoma detection and the ability to refer to baseline images enhances our cognitive comparative recognition abilities (Figs. 18.6 and 18.7) [59, 60]. A study by Banky et al. using TBP detected 311 changed pigmented lesions over a 34-month-follow-up period and 17% of these changing lesions were excised. They found that 26% of these excised lesions proved to be melanomas [31]. It is important to underscore that in patients younger than 50 years of age only 3% of changed lesions proved to be melanomas. In contrast, in patients older than 50 years old, 22% of changed lesions proved to be melanomas. In the same period of time, 262 new pigmented lesions were detected; of these only 4 proved to be melanomas (1.52%) [31]. Interestingly, only 0.4% compared to 30% of new lesions turned out to be melanomas in patients younger and older than 50 years, respectively. Based on the data presented in this study, the overall benign to malignant ratio was calculated to be 2.8; however, the ratio was 4.5 in patients younger than 50 years of age and 0.75 in older individuals [31]. In another prospective trial involving patients at extremely high-risk for melanoma, 770 lesions were excised with a benign to melanoma ratio of 4.4:1. Interestingly, in this study 38% of the post-baseline melanomas were detected as a result of changes noted on comparison to TBP and the median thickness for these melanomas was 0.33 (range, in situ to 0.83 mm) [17]. Another study investigating 576 high-risk patients showed that 35% of lesions excised due to changes noted on comparison to baseline TBP proved to be melanomas with the thickest lesion having a thickness of 1.1 mm (21 of 27 melanomas were in situ). In that study 74% of lesions were biopsied because of observed changes in color or size noted on comparison to baseline TBP and 19% because they were new lesions [50]. Finally, a study of 618 high-risk patients followed over 10 years with TBP and digital dermoscopy showed that 32.4% of lesions excised were detected with the aid of TBP and of these 10.2% proved to be melanomas. It is important to underscore that in this study 40% of all the melanomas detected during a 10-year follow-up period were found solely based on changes noted on comparison to baseline images [18]. This finding emphasizes the importance of TBP for screening high-risk patients by highlighting that up to 40% of melanomas would have been missed by physical examination and dermoscopy alone. Another important point to highlight regarding TBP is that no documented cases of metastatic melanomas have arisen in high-risk patient cohorts followed using TBP and dermoscopy. This is in large part due to the fact that the melanomas found are at an early stage [51]. Similarly, Kelly et al. showed that melanomas found with the assistance of TBP were detected at an earlier stage with a lower average thickness compared to the general population [49]. This was also demonstrated in another study, which showed that TBP helped in the detection of early stage melanomas with

53.3% of cases being in situ melanoma and with no melanomas having a thickness of greater than 1 mm [19].

2. *Reduction of unnecessary biopsies:* Although directing efforts toward maximizing the sensitivity for detecting melanoma is important, it is just as important to also channel efforts toward improving specificity. Reducing the number of non-cancerous lesions being biopsied will have a positive impact on morbidity and health-care costs. One study compared the rate of biopsies before and after introduction of TBP into the pigmented lesion clinic. They found that TBP led to a 3.8-fold reduction in the number of nevi biopsied (5.92–1.56 mean biopsy number per patient after >5 years of median follow-up) [25]. Interestingly, younger age (<30 years) was associated with higher biopsy rate (which may be explained by the higher volatility of nevi in younger individuals) [25, 61, 62]. This study also underscores the need to always evaluate the benign to malignant ratio keeping the absolute numbers in perspective. This is highlighted by the data suggesting that despite the positive impact of TBP on reducing the absolute number of biopsies of nevi, the nevus/melanoma ratio increased after TBP from 7.7 to 14.3. This can be explained by the fact that while TBP helped reduce the overall number of biopsies performed, it also led to the targeted biopsy of a smaller subset of benign but changing lesions [25]. Approximately 50% of melanomas were in situ; invasive melanomas had a median Breslow depth of 0.38–0.51 with no melanoma thicker than 0.72 mm. In contrast, pre-TBP melanomas had a median depth of 0.4–0.7 with cases reaching a thickness of 3 mm [25]. Similar to what has been shown in numerous other studies, most changing lesions will prove not to be melanoma (Fig. 18.4), and this reinforces the need for continuing efforts aimed at improving specificity with technology such as digital dermoscopy, RCM, and electrical impedance, among others [19, 25]. In yet another study, there were less excisions performed in the photography group compared to the control group (33% vs 35%; $p = 0.006$) [52]. While the number of excisions were fewer in the TBP group, there were more non-melanoma skin cancers (NMSC) excised (58% vs 42%; $p = 0.005$), fewer benign pigmented (21% vs 23%; $p = 0.005$), and non-pigmented lesions (20% vs 32%; $p = 0.005$) excised in the TBP group compared to the control group [52]. There is one study documenting that TBP may not actually decrease the biopsy rate. Risser et al. did not show a decrease in biopsy rate with the use of TBP; however, it is highly probable that the follow-up period of only 1 year in this study may not have been long enough to appreciate any substantial differences [63, 64]. All other studies have in fact shown a decrease in the biopsy rate. A study evaluating 618 high-risk patients followed up with TBP and digital dermoscopy found a melanoma to benign ratio of 1:10.75 with a mean of 1.86 excisions per patient during a median follow-up period of 96 months (8 years). Two thirds of the lesions excised in this study were removed because of changes noted during monitoring, and one third were removed because they were new lesions [19]. In another study by Goodson et al., TBP was compared to digital dermoscopy monitoring and the results showed lower biopsy rates (0.59 vs 1.1 per patient) and lower benign-to-melanoma ratios with TBP compared to digital dermoscopy. Moreover, TBP was associated with higher melanoma detection (4.4% vs 1.9%) [53]. The results of this study highlight the fact that TBP and dermoscopy are complementary and act synergistically in finding melanoma.

3. *Promote self-skin examination by patients and reduce patient's anxiety*: According to some studies, the majority of melanomas are detected by the patient, their partner, or family members [54, 65–68]. Encouraging patients to take an active role in melanoma detection by promoting self-skin examination may greatly enhance early detection of melanoma [69, 70].

Although the use of TBP remains primarily in the hands of physicians, the use of TBP may make patients more compliant at performing skin self examination (SSE) [54]. SSE has the potential to reduce melanoma mortality by 63% [71] and is associated with a sensitivity of between 25 and 93% and a specificity of between 83 and 97% [72]. The simple existence of TBP improved the rate of SSE by a factor of 3.4 [73]. One study demonstrated that after training patients in the use of TBP and performance of periodic SSE, there was a 51% increase in the frequency of SSE [55]. It should come as no surprise that patients with a history of skin cancer were more likely to use their TBPs during SSE [56]. In another study, 53.4% of patients believed that regular SSE helped in detecting melanoma, and 31.1% found TBP to be a useful means toward finding early melanomas. The use of mole-mapping may improve SSE accuracy by a factor of 2 compared to regular SSE [74]. Although patients are capable of finding melanoma, some melanomas are overlooked, especially in those patients that have many nevi. Fortunately, these melanomas can be discovered by their dermatologist [58]. In one study, 30% of melanomas were identified by patients during photography-aided skin self-examination and 70% were found by the clinician [50]. This underlines the importance and synergy between periodic SSE and periodic physician based skin examinations.

Regarding patient perspective on TBP, Secker et al. performed a study focusing on the patient's point of view regarding TBP in a population where 1/3 of the participants had a personal or family history of melanoma. Three hundred and eleven patients were asked to perform complete body examination every 2 months. Approximately 40% of patients reported that they lacked the confidence and capability to detect new and changing lesions. Only 10.9% were confident at being able to recognize skin cancer. Furthermore, 69.4% reported that performing complete SSE was nearly impossible and approximately 28% of patients felt embarrassed by their photographs and did not use them. Only 6.2% of participants reported using TBP every time they performed self-skin examination [58]. While 78.9% of patients preferred a dermatologist to perform the skin examination, the easy availability of emerging technologies such as Smartphones and apps to store and use TBPs may facilitate getting more individuals engaged in self-skin examinations [73, 75]. Another benefit of TBP is its ability to reduce patient anxiety regarding their skin. Simply knowing that their clinicians have objective data in the form of TBP to help guide the skin examination is a tremendous comfort to many patients [76].

In our center, the baseline TBP images are acquired on most high-risk melanoma patients. During subsequent follow-up visits, the patient usually stands next to computer monitor, and the clinician compares the patient's skin and nevi to the baseline images. Other centers will perform a routine skin examination and refer to the TBP only when a questionable lesion is discovered to determine whether the lesion is new or has changed. And yet other centers will acquire repeat TBPs at periodic intervals and compare sequential TBPs on a computer monitor after the patient's routine visit is complete. If new or changing lesions are found, the patient is informed to come back for the evaluation of those lesions.

18.4 Limitations

The main limitation of TBP is that its impact on biopsy threshold and its usefulness in detecting melanoma is contingent on the patient coming back for follow-up visits. Physicians are more likely to monitor as opposed to biopsy ambiguous lesions knowing that TBP exist. In essence, when TBPs are present, physicians are lowering their sensitivity for melanoma detection during the first visit in exchange for maintaining a high specificity. Dermatologists using TBP rely on change detected during follow-up to help guide which lesions to biopsy. Thus, early melanomas that may have been missed during the first examination will be discovered due to changes noted during the follow-up examinations. This in turn results in clinicians regaining their sensitivity while maintaining a high specificity for melanoma detection. However, this heightened sensitivity and specificity is contingent upon the patient being compliant with their follow-up visits. This phenomenon was reported in a randomized trial that showed that physicians relying on TBP are more likely to monitor atypical lesions compared to physicians that did not have access to TBP (37% vs 29%; $p = 0.006$). This resulted in a lowering of diagnostic sensitivity but an increase in specificity during the first visit for the clinicians using TBP. However, the loss of sensitivity was regained during follow-up visits. Taking follow-up visits into account, both the sensitivity and specificity was higher in clinicians using TBP as compared to clinicians not using TBP [52].

Some argue that use of TBP is time-consuming and posit this as a limitation that prevents them from using TBP. Others are anxious that they will miss suspicious or changing lesions due to errors of perception. They fear that having TBP may provide evidence that they missed a lesion that ultimately proves to be melanoma and that this may be used in litigation against them. While these concerns are understandable, there have been no such litigation cases to date that we are aware of. The aforementioned barriers to the use of TBP may soon be addressed by computer vision. Efforts are underway to create robust computer-assisted technologies aimed at rapidly evaluating TBP and highlighting lesions that are new or have changed, allowing the clinician to focus on only these dynamic spots (Fig. 18.10). In addition, the cost of the equipment and the time required to acquire the images may also be a limiting factor.

18.5 Conclusion

TBP is a valuable tool that can improve the sensitivity for finding early melanoma via the detection of changes noted during follow-up visits. TBP also reduces the level of concern for lesions noted to be stable during follow-up, which translates into lowering of the number of benign lesions removed.

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Photography in Plastic Surgery

19

Francisco Solesio and Ibrahim Fakih

Contents

19.1 Introduction

The use of images is frequent in our daily practice to graphically document both the results of an operation and the preoperative appearance of the patient. The use of illustrations for medical purposes dates back to ancient times. Civilizations as old as the Egyptian, Greek, and Roman gave us medical illustrations. Later, during the Renaissance, in the book by Gaspare Tagliacozzi entitled *De Curtorum Chirurgia per Insitionem* (1597) (On the Surgery of Mutilation by Grafting) (Fig. 19.1) he described the surgical method that bears his name for nasal reconstruction in two stages, this being considered the first exclusive treatise on plastic surgery [1]. The illustrations of postoperative bandages in this book are iconic in this specialty.

However, the accuracy, credibility, and fidelity of illustrations take a great leap forward with the introduction of photography into the medical world. This practice continues to rise due to the widespread use of mobile phones and the convenience of taking images with these portable devices. Although the use of digital reflex or digital reflex cameras (DSLR) is still the most

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Fig. 19.1 Illustration from *De Curtorum Chirurgia per Insitionem* showing Tagliacozzi's postoperative bandage. (From Wellcome Collection, Attribution 4.0 International (CC BY 4.0))

suitable option for the graphic documentation of patients thanks to the high-quality images that are obtained, mobile photography is undoubtedly convenient and accessible. Therefore, it is becoming very common to find images taken with these devices.

The level of standardization of medical photographs increases with the passage of time, although this has not always been the case. The use of medical photographs of patients dates to documents approximately 150 years ago. Gurdon Buck (1807–1877) is considered the first surgeon to publish an article with preoperative images of his patient back in 1845 [2]. Subsequently, a Berlin traumatologist named Behrend used pre- and postoperative images of a patient in 1852 to compare surgical results [3]. Janos Balassa, professor of surgery at the University of Budapest, published a book in 1863 describing nasal reconstruction in two stages using photographs. This appears to be the first photographic record of a reconstructive plastic surgery procedure [3].

With time, the use of photographic cameras for the documentation of medical images became increasingly popular. Nowadays, it is unimaginable a plastic surgeon patient file without before- and after surgical images. Technological advances have undoubtedly been, together with lower costs, the main drivers of this upward trend.

As Sir Harold Gillies said during the first international congress of plastic surgery in Stockholm, "photography has been one of the most important advances in plastic surgery" [4].

To have two comparable images, e.g., to compare the result after a surgery, some degree of standardization is indispensable. Different variables influence the end result of a patients' photograph, such as patient-to-camera distance, illumination, exposure, focus, choice of background, angle of the shot, etc. Any difference in these parameters can give a false information. It is essential that photographic conditions are standardized to obtain images that are reproducible, in controlled conditions, eliminating confusion or false results.

Despite the existence of various scientific articles published in relation to standardization, images taken without control of the photographic parameters are still common in scientific conferences and publications, making the results and conclusions obtained from the images less valid.

The elements listed in this chapter are essential for taking good-quality clinical photographs. For each of them, we will recommend our ideal option and some useful tips, though we are aware that individual modifications can be done depending on the available resources. It is not about sharing the same photographic parameters that is important, but that each one of us establishes certain parameters and maintains them over time in our daily practice.

19.2 Equipment

19.2.1 Camera

When a beam of light falls on an object, it is reflected in all directions. Among the reflected beams, those that are directed at our camera are the ones that will form the image we capture. This reflected beam will first pass through the objective lenses (which would be equivalent to the cornea and crystalline lens), then it will pass through the diaphragm, which is responsible for limiting the amount of light that will pass (being the equivalent of the iris of the eye). After passing the lens, light will have to go through the shutter curtains. In SLR (Single Lens Reflex) or DSLR (Digital Single Lens Reflex) cameras, the image, once it has passed through the lens, hits a mirror and is reflected towards a pentaprism that deflects the beam of light towards our eye. The image captured through the optical viewfinder is the same as the one captured by the digital sensor. When we press the shutter button, the mirror is raised and the beam of light passes between the shutter curtains falling directly to the digital sensor or photographic film (See Chap. 10).

Today, there are digital cameras that do not need an optical viewfinder and can use the same digital sensor to show the image that we are going to frame through the LCD viewfinder or LCD screen making the mirror and pentaprism unnecessary. These cameras are called **MILC** (Mirrorless Interchangeable Lens Camera), **EVIL** (Electronic Viewfinder with Interchangeable Lens), **CSC** (Compact System Camera), **MSC** (Mirrorless System Camera), or **DSLM** (Digital Single Lens Mirrorless).

Cameras have evolved very quickly since their first appearance in both their fundamental elements: the body and the lens. The objective could be compared to an eye where the image is captured and sent to the body of the camera that would be the brain, where the image is processed and recorded.

In the objective we find the lenses and the diaphragm and in the body is where most of the controls and elements for controlling the photographic parameters of the image are located. These controls act on the aperture, shutter, and sensor sensitivity. We also find on the body the shutter curtains, the mirror and pentaprism (if present), the sensor (comparable to the camera's retina), the viewfinder and the LCD screen, and the image stabilizer (alternatively, this element also may be in the lens).

To take good photographs, it is essential that the camera includes the following features. Most of them are found in any high-end camera:

- White balance control: used to calibrate the color tone of the image by calibrating its white component. Image color is affected by the color of the incoming light, so it is important to calibrate the white balance to obtain images with true colors.
- Exposure control: this parameter is useful when the background brightness is different from that of the subject being photographed. For example, photos of patients with Fitzpatrick skin type III or above on a white background and vice versa.
- A resolution (number of points that make up the image) of at least 16 megapixels is especially useful for producing bigger format photos. On the other hand, it must be considered that the higher the resolution, the larger the image's file size.
- Optical Zoom of at least 4 optical magnifications (4×) (do not confuse with digital zoom that is simply an enlarged crop of the image).
- LCD screen must be large enough to clearly see the result (usually 2.5–3 in. at least), though digital zoom will be needed frequently to check image details.
- Sensor size (equivalent to analog camera film): larger sensor sizes give higher-quality images (size is higher in reflex cameras than in compact ones, and even smaller in mobile phones).
- Macro focus function.
- Grid lines: although most cameras have the function of displaying framing guides, it is possible that these do not fit our needs, so an inexpensive and simple way to solve this problem is to make your own template. To do this you can cut a transparent acetate sheet the

size of the LCD screen, and print on it the guide lines that you consider appropriate (e.g., vertical line, horizontal line, top line, etc.) and glue it to the LCD screen (Fig. 19.2). This also allows us to generate different types of acetate grids according to our needs and depending on the anatomical region to be photographed (Fig. 19.3). These grids will help more effectively to perceive existing asymmetries, as well as framing in a more standardized way. This is the first step to find consistency and reproducibility in our photographs.

Fig. 19.2 Adding a personalized grid to the camera

The other main part of the camera is the lens barrel. The lens sets the image magnification, focus, and controls the amount of light that hits the camera body. A brighter lens will give more independence from external lighting. It is important to have a very bright photographic lens, that is, the one with a bigger opening of the diaphragm. The brightness of the lens is determined by the lens' design. Normally, at the edge of the lens, we can find some of the technical specifications. Among these we will see a parameter with format 1:#. We should look at the number after the colon. A brighter objective will have smaller numbers. For example, in case of seeing a lens with 1:3.5 and another with 1:2.1, the second lens has greater luminosity (maximum aperture of 2.1) than the first one (maximum aperture of 3.5). A brighter lens will let you take pictures in darker situations without the need of flashes or external lights; also, it allows to freeze images and avoid blurring by using faster shutter speeds.

It is common to use vari-focal length lenses (commonly referred to as zoom lenses). For clinical use, a X4 zoom (4× optical magnification) is sufficient. This tells you that its maximum focal length is four times greater than the minimum focal length.

Fig. 19.3 A grid is used to correctly frame the patient using anatomical landmarks such as middle line or Frankfort's line. It is possible to draw grids with different designs

Although the ideal option would be to have a camera with interchangeable lenses and to be able to use the most appropriate lens for each situation, we must bear in mind that making frequent lens changes is annoying just as it is transporting too much photographic equipment from one place to another (consultation room, surgery room, emergency room, and so on). Therefore, we must find a balance between photographic quality and technical simplicity to have good results without turning the photographic process into something cumbersome. Never forget, the worst photo is the one that is not taken; it is important to choose equipment that does not dissuade us from taking images due to the laboriousness of the process or the inconvenience of transportation. Therefore, we must consider sacrificing photographic quality for the sake of comfort to have reproducible results easily, but always maintaining good quality. A camera we do not carry when we want to take a photo is not an option.

Smartphones are a convenient and practical solution. They fit easily in the pocket, are lightweight, are fast to operate, and can be readily connected to the Internet. Despite all the advantages, they are not recommended for professional use because of several facts: (a) the image quality can be inferior than DSRL; (b) the technical parameters are not usually configurable; (c) images have more distortion as the focal distance does not go beyond 3–5 mm; and (d) most important of all, they can serve as entry points for data theft [5]. Even so, the best camera is the one you have with you, and smartphones are regularly available making them a better alternative than nothing.

Some other technologies such as thermal imaging and 3D photography deserve mentioning in this text (Chaps. 30 and 31). Chubb et al. suggest the use of thermographic photography to identify the location of individual perforator arteries saving costs and risks of CT scan [6]. For this purpose, they introduced a technique that is readily available and easy to implement for preoperative imaging, with an accuracy that matches the more advanced imaging modalities. Thermal imaging enables prompt operative planning and avoids the need for delays in imaging, confusion in interpreting a radiologist report, and the need for intermediary radiologists altogether.

The advantages of 3D photography have been described by Weissler et al. [7]. It helps assess volumetric analysis and geometric parameters, including depth and surface topographic distance measurements. It also allows 3D printing of specific anatomical areas of the patient. However, it is not widely spread among surgeon’s practices, and up to this day its use is basically reduced to enhance preoperative consultation with surgical simulations as a marketing tool.

19.2.2 Sensor

It is the element that converts the beam of light into an electrical signal. There are different sizes of sensors from Full Frame to 1/3.2″. With a larger image sensor, one obtains a better image quality. Mobile devices contain smaller sensors (1/2.55″ in the best of cases) and in consequence loss of image quality, in spite of being very handy. Cameras with Full Frame and APS-C sensors give superior image quality.

19.2.3 Case

When intraoperative photos (Chap. 27) should be taken, it is essential to ensure aseptic management of the camera. For this purpose, several methods have been proposed, e.g., plastic bags, double gloves, tripods, circulating personnel, etc. Garca-Rabasco et al. proposed the use of a sterilizable underwater housing, which can be operated by the surgeon and placed as close to the patient as needed. Infection risk is avoided thanks to its sterile case [8].

19.2.4 Tripod

The tripod is an image stabilizing element that reduces the relative movement between the patient and the sensor. Normally, a photo taken by hand should be taken at a speed greater than

1/60 for photographers with a good pulse and 1/125 for most people. The faster the shutter speed, the less light will be captured, resulting in a darker image. We can correct this by increasing the sensitivity (ISO), but this correction will lead to a reduction in image quality by increasing the grain. The use of a tripod allows us to take better shots by eliminating the movement of the photographer, but it does not correct small movements that the patient may make. A bright lens allows the image to be captured in a shorter time interval giving less time for the patient and photographer to move giving as a result a sharper image.

A technological innovation that is increasingly present in modern cameras is the image stabilizer. It consists of physical mechanisms that correct the vibration and movements of the camera. These mechanisms can be on the lens or on the camera body. The advantage of being in the camera body is that interchangeable lenses without stabilizer can be attache (these lenses tend to be cheaper). On the other hand, the advantage of being on the lens is a greater precision of image stabilization given that they are calculated for that specific focal length. Having an image stabilizer allows us to avoid using the tripod, which in small spaces can become a cumbersome piece of equipment. Whether or not a tripod is used, it is convenient to mark on the ground the different locations from where the images will be taken for greater standardization.

19.2.5 Backdrop

The composition of the backdrop is decisive to achieve a standardized collection of images in our archive. It is important that it does not have distracting elements such as objects in the office, windows, other people, baseboards, doors or blinds, together with a uniform lighting and a similar degree of luminosity to that of the patient's skin (Fig. 19.4).

For Caucasian patients, the ideal backdrop is sky blue [9–11] or neutral gray (that which reflects 18% of the light it receives) because automatic exposure tends to make everything 18% gray [12]. A darker backdrop will subtract light from the image causing the camera to compensate for it with increased exposure resulting in an overexposed image in the patient area. On the contrary, a backdrop lighter than the patient's skin will cause the patient to be underexposed. When using a backdrop with a different brightness than the patient's skin, it may be necessary to manually compensate the exposure value (EV).

To avoid the appearance of the skirting boards or the change of color from the wall to the floor,

Fig. 19.4 A plain backdrop avoids distraction caused by some office's items (left and center). Right: A plain backdrop is recommended to avoid distractions. (Reproduced with permission of Cirugia Plastica Iberolatinoamericana)

it is convenient that the element that forms the backdrop (paper, cloth, etc.) passes under the patient's feet going forward in the direction of the camera. Typically, a backdrop roll is used whose length exceeds the distance to the ground by 80 cm; it is made with a matte fabric to avoid light reflection.

19.3 Standardizing the Image

19.3.1 Lighting

Lighting is the most important external element for good image quality. Good lighting should avoid shadows, but without flattening the image too much. Consistent lighting conditions throughout all images allow for comparable photos. In turn, if the lighting is sufficient, the shutter time will be shorter and blurred images will be avoided.

Until a few years back, lighting was achieved through incandescent bulbs that concentrated a lot of light, which required the use of umbrella-type diffusers or softboxes. Nowadays, with the use of LED panels, we achieve reasonable-sized lighting sources in which the color temperature can be controlled, also adding the benefits of low electricity consumption and less heat emission. These panels can be placed on a tripod allowing the height to be adjusted and placed in the location we need within our practice (Fig. 19.5).

The ideal recommended distribution is a symmetrical distribution of light filled with two main sources at 45° from the subject (one on each side and therefore forming 90° between the two sources) and one or two accessory sources behind the patient to illuminate the backdrop [9]. By doing so you can manage to eliminate the shadows projected on the backdrop. We recommend that the main lights be at the same height as the camera. This lighting scheme will eliminate the shadows but will flatten the image. If we want to appreciate irregularities (acne, lipomas, wrinkles, etc.), other lighting angles are needed (Fig. 19.6).

Other authors, such as Meneghini, propose the use of a single flash mounted on a pantograph that hangs from a rail on the ceiling to place it at different heights with the possibility to slide sideways. It is supplemented with a reflective panel that the patient holds at chest height to eliminate shadows from the lower parts of the head [13].

Fig. 19.5 LED panels are available to light the patient

It is important that the light sources are not point lights, as they would create harsh lighting. Instead it is recommended to use soft lighting that nuances the shadows. For this, diffusers or sources composed of LED panels are used.

In case only one flash (the one in the camera) is available to light the subject, you can always turn the camera placing the flash in the most convenient position with respect to the lens to hide shadows [14]. For example, if we want to avoid annoying shadows when photographing a face from the left side of the patient, we must place the flash to the left of the lens by turning the camera 90° counterclockwise (Fig. 19.7). This procedure should be done only if we do not have another source of better lighting, since it is not advisable to use only the camera's built-in flash.

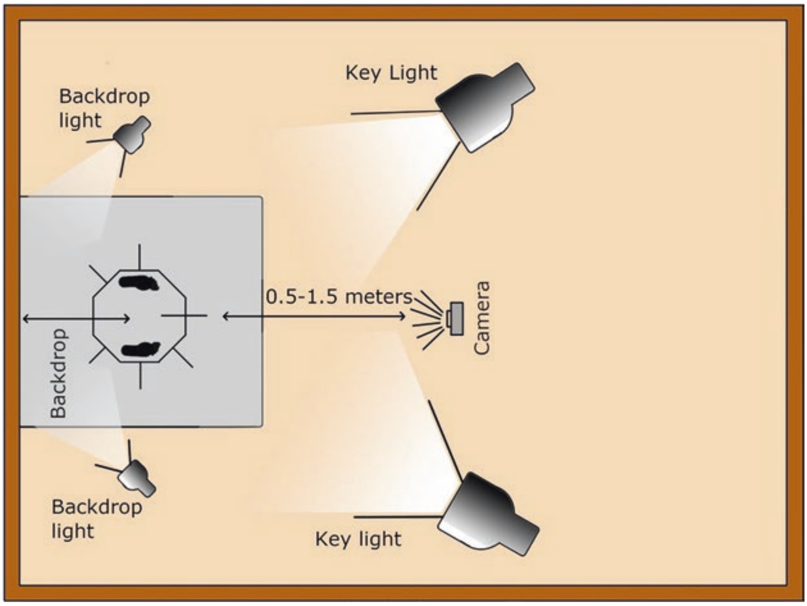

Fig. 19.6 Photography room blueprint. (Reproduced with permission from Cirugia Plastica Iberolatinoamericana)

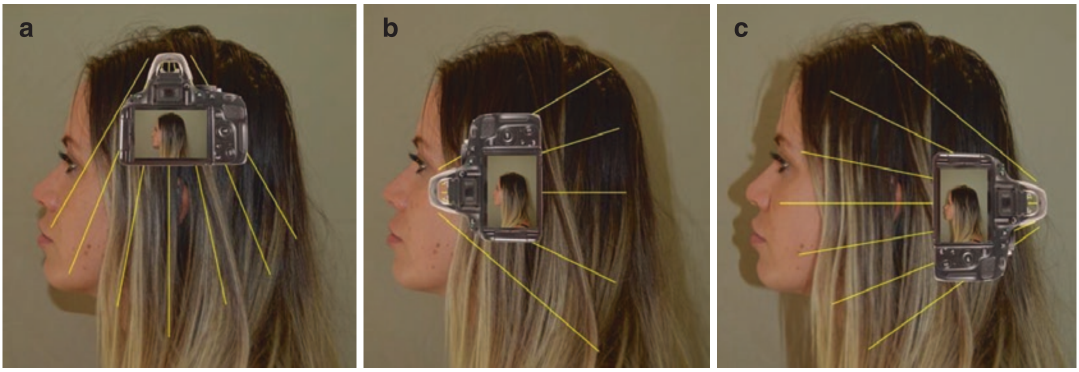

Fig. 19.7 Taking clinical photographs with traditional flash positions can cause unwanted shadowing on the backdrop (**a** and **c**). Repositioning the camera so that the flash changes direction can eliminate problematic shadows (**b**)

In summary, camera's flash should be our last option, being annular flash a better one. Multiple led panels outperform any other option.

When it is necessary to photograph cavities such as the mouth and palate, it is normal for the shadow of the cavity wall to be projected in the cavity if adequate lighting is not used. For these situations, the best solution is to use a ring flash that consists of a circumferential light source that adapts to the edge of the camera lens. Instead of casting a shadow on the cavity, it will fill the cavity with light, making the interior visible (Fig. 19.8).

19.3.2 Exposure

A correct exposure setting will allow to faithfully reproduce real skin tone avoiding deception. Digital cameras automatically adjust the amount of light received from the image by varying exposure. Normally there is a setting that allows us to select which area of the image is representative of the total brightness. Some cameras permit selection of a spot area, a central area or the entire image, for the exposure sample. On other occasions, there are more selective options. However, to make the adjustment, cameras sometimes use

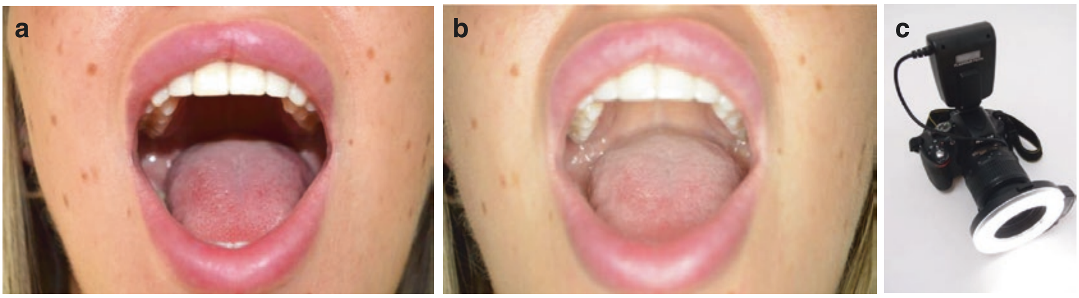

Fig. 19.8 Ring flash is useful to take photos of hollow places. (**a**) Left image: regular flash; (**b**) central image: using ring flash; (**c**) example of camera with ring flash

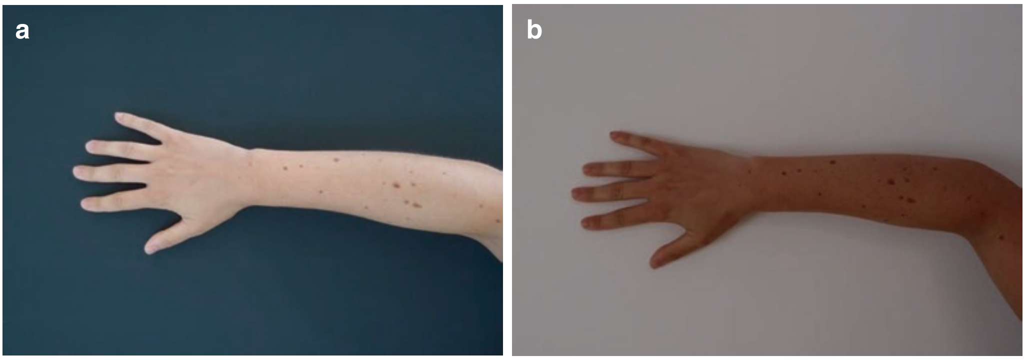

Fig. 19.9 On the left side (**a**): a dark backdrop makes the skin look lighter while (**b**) (right side) a light backdrop makes it look darker. Automatic exposure has been used in both pictures

an algorithm that does not take into account parts of the image we want to see better. Therefore, manual corrections might be required.

Therefore, if we photograph a patient with light skin in front of a very dark background, camera will increase exposure of the photo making the skin look even lighter than it is (Fig. 19.9). On the contrary, when photographing a dark patient on a white background, it will appear darker in the photograph. In the first case, a decrease of exposure is recommended, while in the second one an increase is recommended.

19.3.3 Location

The room where the photographs are taken should be comfortable and spacious. The area dedicated for this purpose must be at least 2.5 m wide by 3 m deep. With these dimensions we guarantee sufficient space to allow us to carry out the different shots under the recommended conditions.

The patient should be positioned close to the wall, but with enough space to be able to unfold the backdrop and place the accessory lighting that will eliminate shadows. Likewise, this distance from the patient to the camera should allow the patient to turn for the 3/4 photos as well as lateral photos. It is also convenient to draw an octagonal template on the floor to assist patient positioning. In case brachioplasty photos are needed, in addition to space left behind the patient some lateral space should be available to extend arms without interference.

The space dedicated to photography must ensure privacy to avoid embarrassing situations; architectural elements that could compromise their privacy, such as translucent glass walls that hint at the patient's anatomy, placing him/her near a door, and open blinds that allow visibility from the street are all situations that need to be avoided. Any situations as the abovementioned compromise the patient's privacy but also represent a disturbing lightning element. In this situation, meteorological or time differences can generate differences in the global illumination of the photographs that would go against standardization.

19.3.4 Patient's Position

There are basically two repeating schemes for a photographic standardization. One that includes photos taken at 45° intervals covering a total of 180° (front, ¾, and sides), and another that includes photos taken at 45° intervals until surrounding the patient 360°. The views that cover 180° can be anterior or posterior (Fig. 19.10).

Table 19.1 shows the arches that the most frequent surgeries should cover according to the anatomical area to be photographed. In any of the three options, they must be sequenced every 45°. Specific nonstandardized images may be required for specific details such as a scar, skin lesion, or contour alteration.

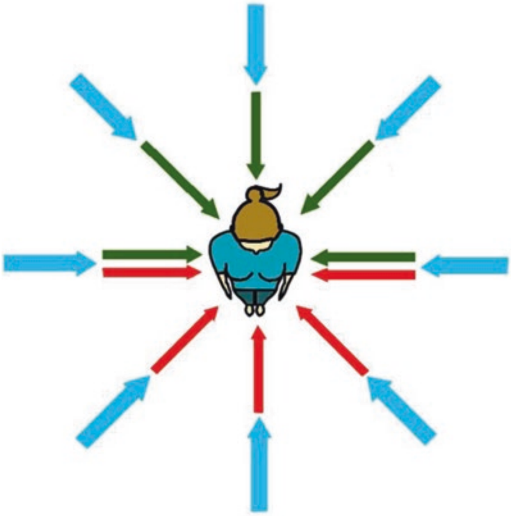

Fig. 19.10 Blue arrows indicate pictures taken at 360° in 45° intervals. Green arrows show angles of pictures for posterior 180° images. Red arrows show angles for anterior 180° images

The camera (placed on tripod or handheld) should be located over the marked positions. Ideally, the body part that needs to be photograph is at the same height as the camera, so we must indicate to the patient the desired positioning according to our purpose (standing, sitting, lateral ...). It is important that the lens is horizontal avoiding tilting the camera up or down when framing an image. If you need to seat the patient, it is best to use a rotating stool. This is typical setting for head photography (e.g., ears, eyelids, nose, full facial).

The Plastic Surgery Educational Foundation recommends the use of floor tape marks with an octagon pattern to be kept constant relative positions of patient and camera [15]. It proposed the use of a 30 cm side octagon with radiating lines for proper positioning of the patient (Fig. 19.11). One of the lines is extended out along the camera axis and marked at appropriate distances. These distances are the ones to be used for photographing specific anatomical areas.

Whenever the patient is going to stay seated, we recommend the use of an adjustable height stool (with no back) placed over the center of the octagon. The height should be one that makes the area to capture to be at the same height as the camera's. The feet of the patient should be placed on either side of the appropriate radiating line. For a front view, the patient looks directly into the camera lens. For lateral or oblique views, the patient looks at a tape mark or a bull's eye placed on the wall [12]. Whenever the patient is standing, his feet should be placed on the inner side of opposite edges of the octagon keeping the same distance as the shoulders.

Table 19.1 Angles that need to be included for a given anatomical area

Angle	360°	180° posterior	180° anterior
Anatomical area	Arms Legs Abdomen Ears	Back Buttocks Calf	Eyelids Nose[a] Full facial Neck Chest

[a] In rhinoplasty pictures it is convenient to take also worm's eye view and bird's eye view

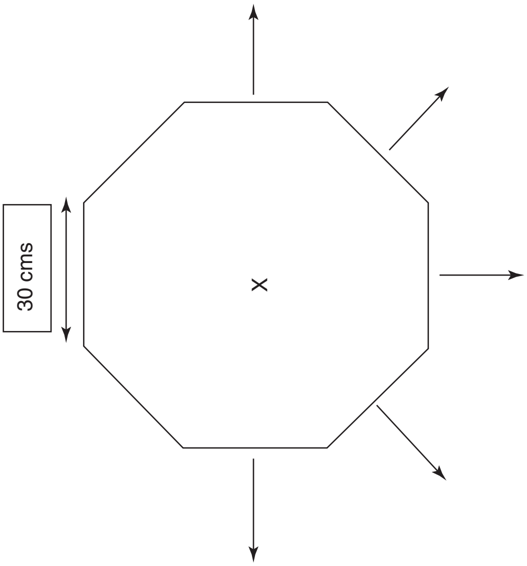

Fig. 19.11 A 30 cm side octagon is used as landmark to position the patient

19.3.5 Distance

One of the goals of standardized photography is to maintain consistent magnification from photo to photo. For a given camera system, this may be achieved by controlling the distance from camera to the patient. However, the distance required for a given magnification is not the same for all camera systems—it is affected by the size of the imaging sensor and the focal length of the lens [15].

Depending on the distance at which the shot occurs, the distortion suffered by the model varies. In close-up images, fractions closest to us will appear bigger than they really are, and more distant ones will appear smaller, creating an effect called "reflection in a Christmas tree ball." For this reason, it is advisable to keep a distance from the patient of at least 1 m and enlarge the image by using the optical zoom rather than staying close to the patient without using magnification. Images taken from a distance and magnified with zoom are less distorted than images without zoom and shot at a shorter distance. Placing some marks on the floor will help you mantain the same shooting distance.

Normally a standard distance is around 1–1.5 m. If we use fixed lenses (without zoom) we will have to place ourselves at different distances to obtain the different degrees of magnification required in each of the parts of the body. However, if we use a zoom lens, we can use the different degrees of magnification to adjust the size of the image. In the first case, it is convenient to put some adhesive marks on the ground to indicate the location where we will place the camera and in the second, we use some type of reference to maintain the same focal length. This can be done by adjusting the zoom until a rectangle of predefined dimensions for each anatomical area is framed on the edge of the image or by adjusting the degree of magnification until the zoom frames anatomical landmarks at the edge of the image. These reference points are usually the vertex, chin, navel, shoulders, etc. depending on the region to be photographed.

19.3.6 Focus Points

Cameras with small LCD screens do not allow to clearly see the accuracy of the focus. On larger screens it is somewhat more noticeable, but it is still important to be vigilant when taking the picture to make sure the desired point is focused correctly. When shooting with auto focus, it is common for the camera to mark the focus area used on the screen. Normally, in facial photographs, the camera focuses its focus on the eyelashes as it is a linear element that simplifies focusing by the automated system. Pay attention while photographing a patient from an angle that the eyelashes of the eye closest to you are in focus (Fig. 19.12). In the worm's eye view, it is common for the focus to go to the eyelashes rather than the columella. However, in these shots it is the columella that should be in focus. To avoid this problem, lightly press the shutter button until the camera gets focused (usually halfway through) and then, without releasing the button, back the camera about 5 cm. Then, press completely to take the image. By half pressing the button you have fixed the focus distance and by pressing it fully you have shot with the preset

Fig. 19.12 It is important to check you are focusing on the right spot. The picture on the left shows a blurred focus on left eye while picture in the right shows correct focus on left eye

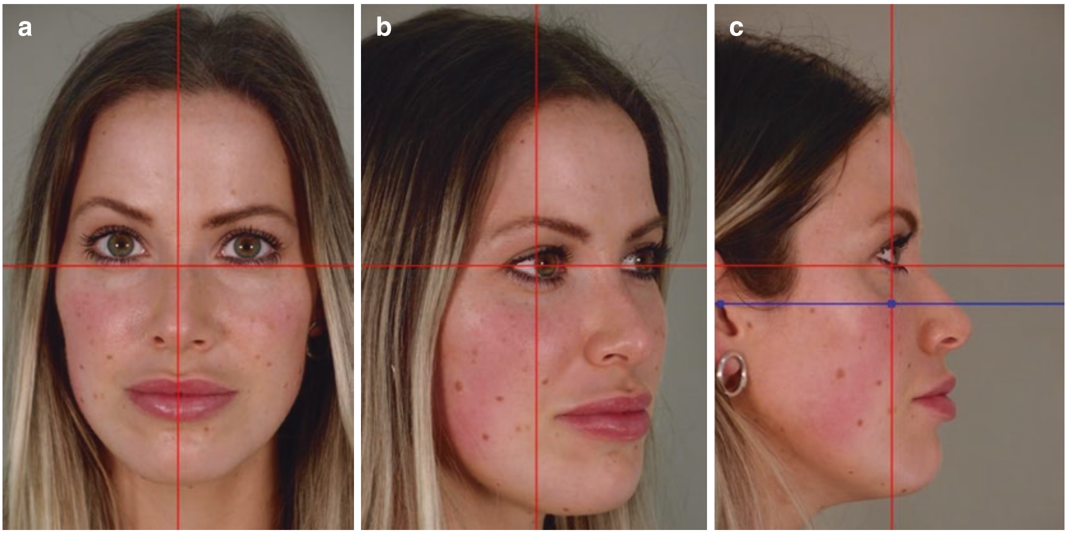

Fig. 19.13 Facial views. (**a**) Front, (**b**) ¾, and (**c**) lateral. The Frankfort's line is marked in blue

focus. By moving the camera with the focus distance locked we will get it to focus on the columella instead of on the eyelashes.

19.3.7 Framing and Tips for Specific Views

In frontal views we recommend matching the body's midline with the screen's vertical midline. The horizontal Frankfort line is another widely used anatomical reference. It is an imaginary line that connects the lower edge of the orbit with the upper edge of the external auditory canal. When possible, this line is used as a reference for a correct alignment of the head position with the horizontal axis of our camera (Fig. 19.13). Typically, the patient is asked to raise or lower their chin to achieve the proper alignment. Also, preestablishing some anatomical references to place near the border of the image when framing (i.e., shoulders, umbilicus, knees, eyebrows, etc.) might be of great help.

19.3.7.1 Specific Tips for Panfacial Imaging

Patients should be seated in a stool to match the patient's face and camera heights. The top of the image should include the vertex and the chin should be near the bottom edge. In the front view,

Fig. 19.14 Left: Nasal basal view (worm's eye view). Notice blue line aligning the root of helix with commissures. Right: bird's eye view is used to visualize nasal dorsum straightness

both ears should fit within the frame, magnification must be as much as possible, and patient's midline should be aligned with camera's vertical midline. Lateral, lateral-oblique, and frontal images should be taken (also worm's and bird's eye views for nasal imaging). In oblique facial and lateral views, we recommend placing the patient in such a position where the nearest eye matches with the screen's vertical midline (Fig. 19.14).

All pictures should be taken using vertical framing with exception of the nose worm's and bird's eye views. A useful tip for close-up nasal worm's eye view is to ask the patient to raise the chin slowly until the mouth commissure reaches the height of the helix's root. This angle of capture is easily reproducible. When taking lateral facial views, an easy and quick way to ensure photographing a reproducible lateral view is asking the patient to fully open his mouth and align our lens with both labial commissures, then ask to close the mouth without moving the head.

19.3.7.2 Specific Tips for Close-Up Eyes Imaging

Horizontal framing is always recommended for this purpose. Eyes images should be made standing close to the patient or using zoom to fulfill the LCD screen with an area of 10 × 15 cm approximately which in the front view must include eyebrows, the whole width of the face, and the whole nose. Also, ¾ and lateral views should be taken. To see the upper eyelids, ask the patient to close his eyes. In case you want to make lower eyelid bags patent, ask the patient to look upwards (Fig. 19.15).

19.3.7.3 Specific Tips for Breast Imaging

The recommended framing for breast imaging should fully include shoulders and umbilicus (at almost the border of the frame), which allows using it later as a relative distance to compare images. Framing should be done horizontally. The camera should be placed at the height of the nipples. A series of 1 frontal view, 2 oblique at 45° angle, and 2 lateral (90° angle) views are recommended. For lateral views, the anterior axillary line should match the screen's vertical midline. In this view, distal breast should be hidden except in cases with noticeable asymmetry. In ¾ view the nearest nipple should match the vertical midline (Fig. 19.16).

One of the most common pitfalls of preoperative drawing of breast surgery is asymmetry due to different shoulder heights. A useful tip for assessing and correcting this malposition and hence evaluating differences in nipple height is to use the camera's grid as a reference. First, match the top edge of the screen with the highest point of both shoulders, asking the patient to raise or lower one or another (or tilting the camera) until a perfect match with the grid is achieved. Then, either using the zoom or by moving farther or closer to the patient, match one of the screen's horizontal lines with the top

Fig. 19.15 Close-up images of the eyes

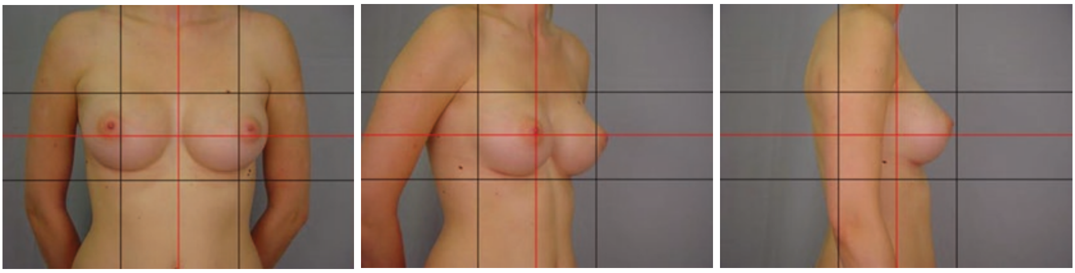

Fig. 19.16 Breast views. (Reproduced with permission of Cirugia Plastica Iberolatinoamericana)

point of one of the new areola's drawing. In case of symmetry, both areolas' drawings should match the line. If only one drawing matches the line at once, then an asymmetrical drawing has been performed. The line passing through one areola will show the symmetrical height in the other breast. Try using this trick to check symmetries in preoperative and/or postoperative pictures (Fig. 19.17).

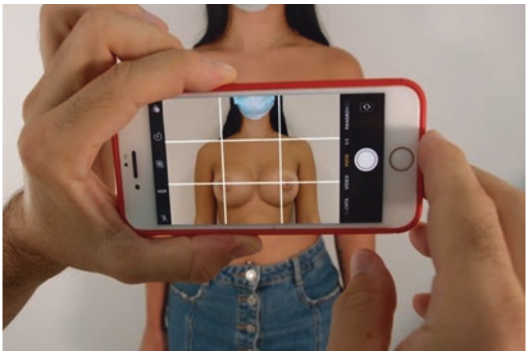

Fig. 19.17 Using mobile phone's grid to check symmetry in nipples position

19.3.7.4 Specific Tips for Abdominal Imaging

Horizontal framing should include from submammary folds to the hips. Pictures should be taken from 360º at 45º intervals plus a bending forward and sitting on a stool in lateral views to expose abdominal flap. In abdominal photographs, it is common for the arms to interfere with the appreciation of the contour of the abdominal flanks or to create shadows on the abdomen. It is advisable to separate the arms from the trunk to avoid such shadows or interferences or having them crossed in front of the chest (Fig. 19.18).

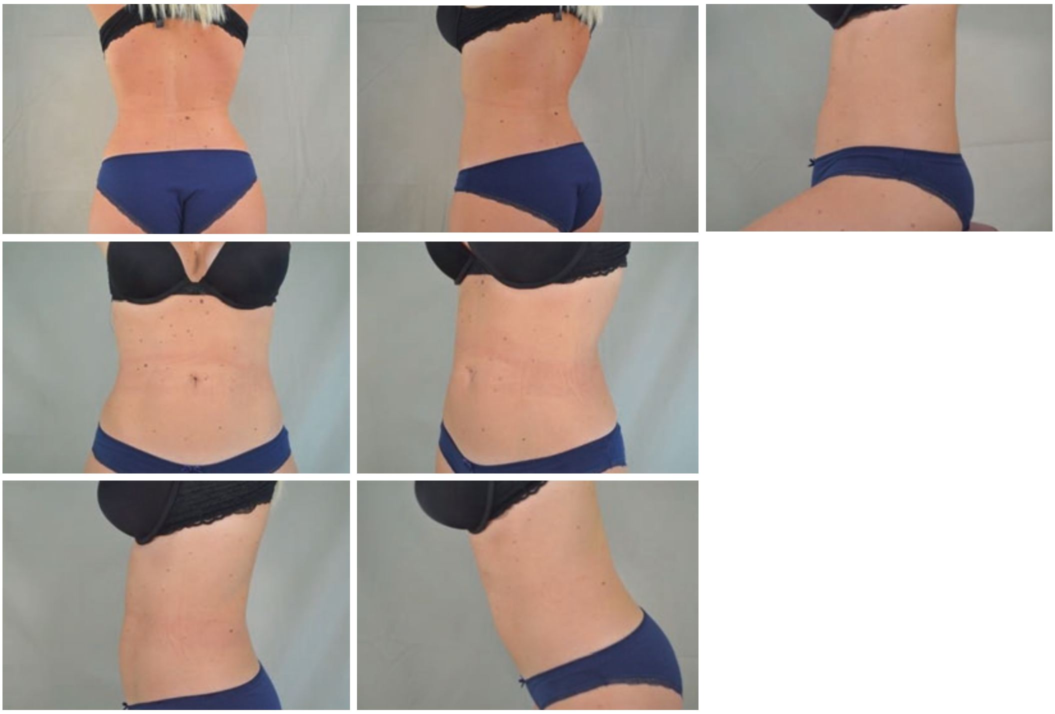

Fig. 19.18 Abdominal views

19.3.7.5 Specific Tips for Hips and Thighs Imaging

Vertical framing is recommended. Patients' longitudinal axis should be centered with the picture. To avoid hands and arms from appearing in the image, the patient should stand comfortably erect with arms folded above the breasts. Feet should be at approximately shoulder width, aligned with appropriate tape marks on the floor and/or walls. Frame should include the umbilicus at top of the screen and knees at the bottom. Pictures should be taken from 360° at 45° intervals (Fig. 19.19).

Specific parameters have been recommended for specific views [9, 13, 16, 17], but most important of all is to mantain the same parameters which meet your photographic needs and are adjusted to your facilities' resources.

19.3.8 Other Aspects

In addition to all of the above, there are certain varied aspects that are easy to ignore if we lose concentration and therefore deserve our attention. Among them, the following stand out:

- Clothing: You should not bother if it is not blocking the vision of the desired area. Clothing must be removed from the area to be photographed. It is common in abdominal photographs to see images of patients with the shirt raised and covering the upper part of the image. In photography of the hands or arms, it is advisable that clothing is rolled up enough so that it does not appear in the image or, better if the patient removes the shirt to fully appreciate the area of interest; and, of course, removing watches, bracelets, and rings. The same goes for pants when photographing thighs; pants must be removed enough so that they do not appear in the image.
- Hair: It must be tied up so as not to interfere with the area being photographed. In lateral photography of the nose it is important that it does not cover the ear, as it is used as a reference element when measuring angles

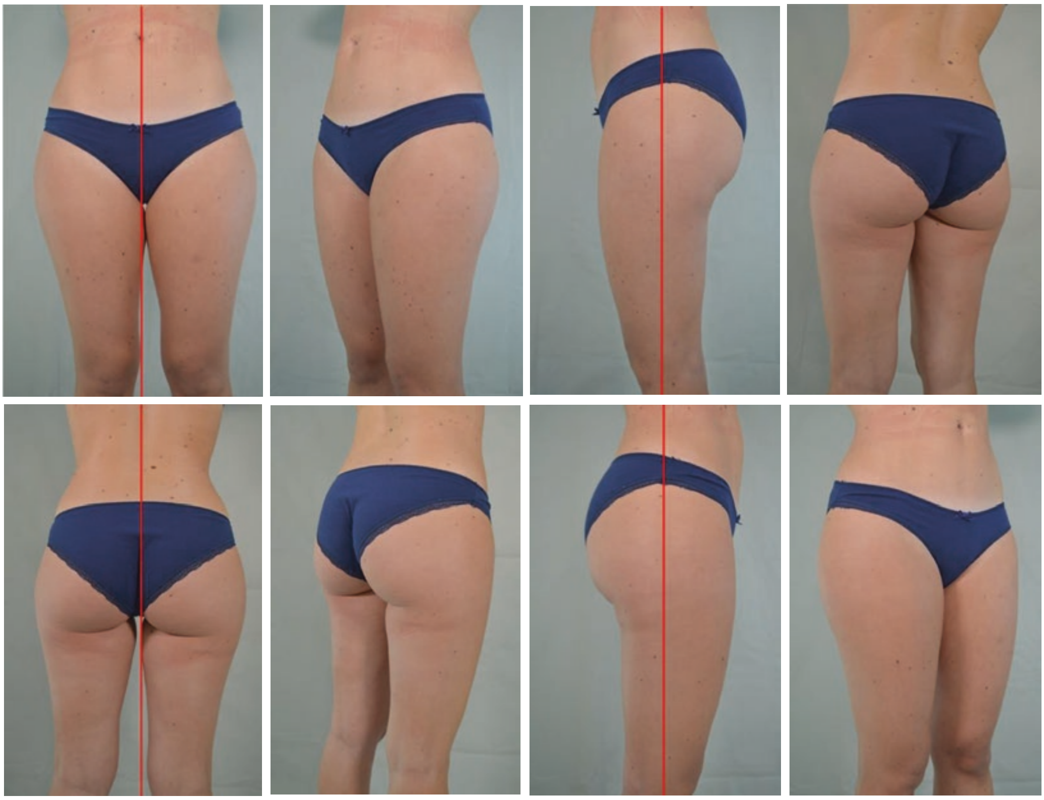

Fig. 19.19 Thigh views

and also to compare distances when wanting to match images with different degrees of magnification. When photographing from behind, hair will cover ears if it is not well tied up.

- Glasses: They must be removed in facial photography as they interfere with the image being shot.
- Makeup: It is acceptable when it is not excessive and does not distract from the subject of the photo. In cases where it is necessary to appreciate the correct color of the skin (ischemia, necrosis, erythema, angiomas, etc.) it must be completely removed.
- Anti-scar or therapeutic patches: They should be removed the day before taking the photos to avoid an imprint of the silhouette of the patch on the skin.

19.4 Video

Currently video has become a very useful tool for the documentation of certain anatomical areas or clinical situations. Today's cameras have increased their image quality when it comes to making videos. These are especially useful for documenting surgical procedures both for educational purposes and for later reviewing details of the surgical procedure.

Sometimes we find structures with complex three-dimensional shapes that are difficult to capture in a static image, and by varying the angle of the shot become evident in a video. Such is the case of nasal ala cartilage after repair surgeries with the use of grafts and resections or alterations of the contour after liposuction.

It is also useful to make videos for the clinical documentation of muscular paralysis and/or paresis, whether iatrogenic, idiopathic, or congenital, and of chemical denervations, such as in the use of botulinum toxin.

19.5 Photography Intervals

Regarding time intervals for taking photographs we recommend, as a general rule, photographic sessions: before surgery, after presurgical markings, and, 1, 3, 6, and 12 months postoperatively.

Complications should also be photographed when noticed, although we may find it unpleasant. Experience shows that this practice can be useful on many occasions. Patients with complications are more reluctant to be photographed at the end of the consultation, especially if they are unhappy with the result or if there is deterioration in the doctor-patient relationship after dealing with the complication. Therefore, in these cases it is advisable to take photographs at the beginning of the consultation when they are still more likely to be photographed.

It is also important to make the photographic record before debriding wounds, removing stitches, performing cures, or other maneuvers that could cause bleeding or alterations in the appearance of wounds.

If the patient must be examined, specifically palpated, it is frequent in those with overly sensitive skin that some erythema appears on their skin after touching them. All the previously exposed reasons justify taking pictures before touching the patient.

19.6 Wireless Memory Cards and Cameras

Wireless SD cards can be used in non-wireless cameras featuring the ability to wirelessly transfer image files to a personal computer. Hence, the data backup process is automated making it more comfortable than connecting the camera to a computer with a cable. The disadvantage is the increase in camera's battery consumption. Modern cameras have an automatic built-in wireless download feature.

19.7 Archiving Images

To easily identify patients photographed and avoid doubts and confusions, we also propose some recommendations for image archiving. In our opinion, one should not write patients' history number on the skin but rename the image file after transferring it to the computer. It has been recommended [18] to use the following format for file name: aaaaaaaa.x.nnn.jpg, where "aaaaaaaa" is the patients' history number, "x" a letter indicative of the photographic session ("a" for the first session, "b" for the second one, etc.) and "nnn" is a correlative number of three digits to distinguish the photos within the same session; jpg is the extension of the image file used. Computer programs for managing and renaming files following this pattern are available. History number contains the date of the first visit using ten digits (first four correspond to the year, next two to the month, and last two to the day), followed by two more digits which number the position, in a sequential order, of new patients on that precise date.

To be able to identify patients until the day you transfer the photographs to the computer, it is useful to take a shot of the clinical history label at the end of the series of images. Similarly, consulting the appointment agenda and the date on which the jpg file was saved can help identification, although to do so, it is mandatory to set date and time of the camera and to account for summer time changes.

There is no need to stamp the date on the image, since most digital cameras store automatically photo's date in the image file along with other technical information in what is called EXIF (Exchangeable Image File Format) specifications.

19.8 Images and Law

Regarding the acceptance of clinical photographs as means of evidence admitted in law, it depends on the legislation in force in each country, so their requirements and validity must be considered. In general, whenever certain conditions are met, the image is accepted as a means of legal proof, which, in turn, can be rejected if its authenticity or possible manipulation is questioned, so it is advisable to adopt precise care to guarantee authenticity.

Another issue related to clinical photography is the consent from the patients to be taken pictures of their body. Only 17.2% of surgeons obtain written consent, 41.4% got it verbally, and 38.5% did not get it at all [19]. It is mandatory to know and follow the applicable laws on each case.

Data theft risk of protected health information is another legal and ethical concern. Smartphones are hackable and their use needs to be carefully considered. When transferring data through a network, the source and destination devices should be password protected. But data transmission should also be encrypted to avoid "man-in-the-middle" data capture. Not all cloud-messaging services are compliant with local health data protection regulations. Cloud storage solutions are a better option for sharing images than direct text messaging, especially when using a HIPAA-compliant (Health Insurance Portability and Accountability Act) service [5].

Due to data theft threat in smartphones when installing risky unnecessary apps, considering purchasing practice-only smartphones can be a good option since it allows administrators to prevent installation of unapproved apps.

19.9 Conclusion

The importance of photographic standardization in plastic and aesthetic surgery has been highlighted in numerous articles [9, 15, 16, 18, 20–23]. Some of them place special emphasis on precise anatomical areas, such as face (Meneghini [13]), body contour (Gherardini [16]), breasts [17], and rhinoplasty (Galdino [24]). Other articles are more generic [9, 12, 23, 25, 26], but they all agree that reproducibility of results is necessary and can only be achieved if the photograph is made under standard conditions, or unchanged ones.

The photographic archive is one of the most precious assets of any plastic surgeon. Small variations can cause noticeable changes and can dramatically decrease the value of clinical photography. Photographic standardization in plastic surgery and aesthetic medicine is necessary to achieve consistent and reproducible results [18]. For this purpose, it is proposed to control various photographic parameters (distance, angle, lighting, etc.).

This chapter aims to show some guidelines for photographic standardization and transmit those that, in our experience, are useful. However, any pattern is correct if it is reproducible.

To obtain an adequate photographic record for documentation, research, legal issues, evaluation of our results, or teaching purposes, it is of crucial importance taking care of your photographic technique and building a consistent and valid photographic archive photo by photo.

A good photographic technique is a habit that can be acquired after taking photos of many patients. It becomes simple and automatic when performed routinely. This is the best way to build a consistent photographic record which will become one of the most important resources for a plastic surgeon nowadays.

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Ophthalmic Photography

20

Alan Frohlichstein

Contents

20.1 Introduction

The Bible states "The eye is the lamp of the body. So, if your eye is healthy, your whole body will be full of light."—Matthew 6:22. The ophthalmologist and optometrist look upon the eye as the window to our physical health. Many times, it is the eye care specialist who detects ocular manifestations of systemic disease, such as high blood pressure or diabetes, and informs the patient of the need for further investigation with their primary care physician. Ophthalmic photographers work with the ophthalmologist utilizing specialized equipment to image various structures of the eye, orbit, and related anatomy.

The first effective instrument to visualize the interior of the eye was the direct ophthalmoscope introduced in December 1850 by Hermann von Helmholtz, MD, (Fig. 20.1). In the simplest

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Fig. 20.1 Helmholtz ophthalmoscope. (Reproduced with permission of the American Academy of Ophthalmology Museum of Vision. All rights reserved)

terms, this allowed looking into the eye the way the patient looks out, just the other direction.

While previous versions of the instrument were created, none had received broad public acknowledgement. Prior to this invention, direct observation of the eye was limited to anatomical dissection. Before 1850, the most common means of training and disseminating information regarding the internal workings of the eye relied upon a hand-drawn atlas of ocular anatomy from anatomical dissection. With the invention of the direct ophthalmoscope, drawings and observation from the examination of living subjects became possible, advancing knowledge in ophthalmology. However, this still did not produce a method of creating a photographic record, and the drawings were always subject to artistic interpretation.

The first reference to a successful fundus photograph of a rabbit eye appeared in 1869 (Jeffries, J.L., Trans American Ophthalmology Society, 1869) [1]. This image is attributed to Dr. Henry Drury Noyes of New York, New York, in the United States who accomplished this in 1862. In 1886, Drs. Jackson and Webster published the first image of a human retina (Fig. 20.2) [2].

In 1926, the Zeiss-Nordenson reflex-free retinal camera (Fig. 20.3) was introduced, providing the first commercially available photographic documentation of the retina. While the appearance, image quality, light sources, and capabilities of these instruments have advanced tremendously since the early days of ophthalmic photography, the underlying optical principles have remained largely unchanged and related to the direct ophthalmoscope.

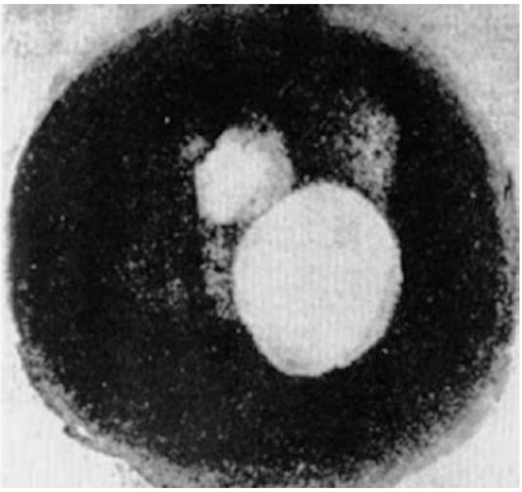


Fig. 20.2 Jackson and Webster's image of a human retina. (With permission Kozak, I Arevalo J.F. Atlas of Wide-Field Retinal Angiography and Imaging, Springer Nature Switzerland 2016 [1])

Since the normal eye is optically transparent, its inner structures may be observed without surgery or other invasive procedures. The basic fundus camera allows observation and recording of the posterior pole of the retina and beyond.

In 1959 fluorescein angiography was devised as part of an experiment introduced by two medical students, Harold Novotny and David Alvis, at the Indiana School of Medicine, in Indianapolis, Indiana. Prior to this, ophthalmic photography was relegated to recording what the ophthalmologist saw, providing its value as a documentation and teaching tool.

Fluorescein angiography brought a new diagnostic ability to the field providing dynamic elements to the study of the retina and choroidal vasculature. For the first time, previously speculated disease processes could be recorded and studied in vivo leading to advances in understanding the interactions of the ocular structures and certain disease and circulatory processes.

The ruby laser (light amplification by stimulated emission of radiation) was invented in 1960 and adapted for use in ophthalmology a year later. Ophthalmologists now had a way to treat many previously untreated ocular diseases

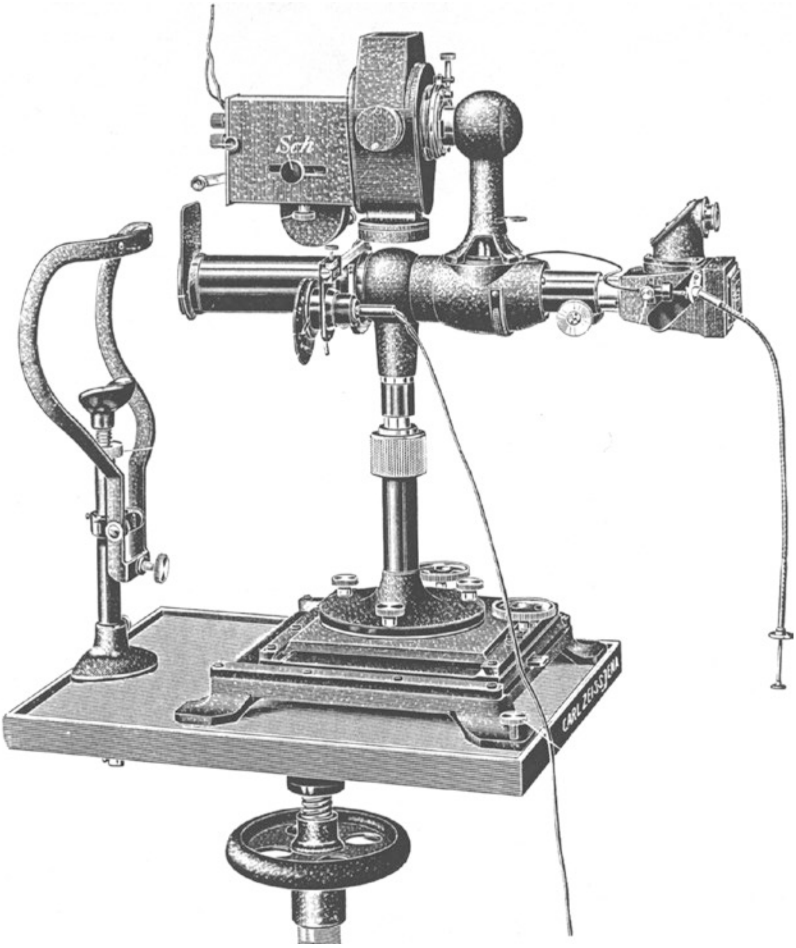


Fig. 20.3 Zeiss-Nordenson retinal camera 1926 (Courtesy of ZEISS Archives)

utilizing fluorescein angiography and retinal photography as diagnosis and treatment guides.

For the next 50 years, fluorescein angiography was the mainstay of ophthalmic retinal diagnostic imaging and only recently has been supplanted by newer imaging technologies. Fluorescein angiography is a relatively noninvasive procedure where fluorescein sodium dye is injected into the patient's vein, usually in the arm or hand, and sequential images are captured as the dye travels through the vascular system. The human eye has two vascular systems. The first is the choroidal circulatory system which nourishes the outer layers of the eye. The second is the retinal circulatory system which nourishes the inner layers of the eye.

Normal profusion of the fluorescein begins with the choroidal circulation usually appearing about 4–6 s post-injection, sometimes producing a choroidal "flush" if the retinal epithelium is not heavily pigmented (Fig. 20.4). This is shortly followed by retinal arterial filling, filling of the retinal arteries, about 6–8 s post-injection (Fig. 20.5) and then capillary filling at about 6–10 s post-injection (Fig. 20.6). The final phase of the transit is the venous filling, about 7–10 s post-injection (Fig. 20.7). About 30 s post-injection, recirculation can be seen, where the dye tends to build up in some structures or pathology (Fig. 20.8). Approximately 6–10 min post-injection, elimination of the dye begins (late phase), as it is filtered out of the blood and excreted in the urine (Fig. 20.9).

For fluorescein angiography, the fundus camera uses a two-filter system. The camera light source passes through an exciter filter which

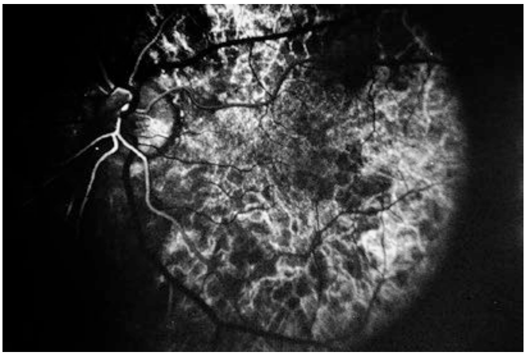


Fig. 20.4 Choroidal filling with early arterial dye

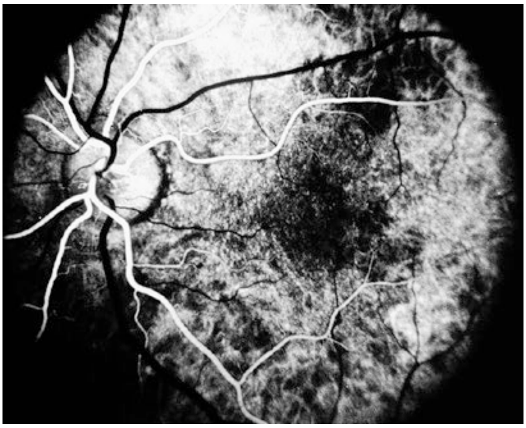


Fig. 20.5 Arterial phase with dye filling the arteries prior to crossing the capillaries into the veins

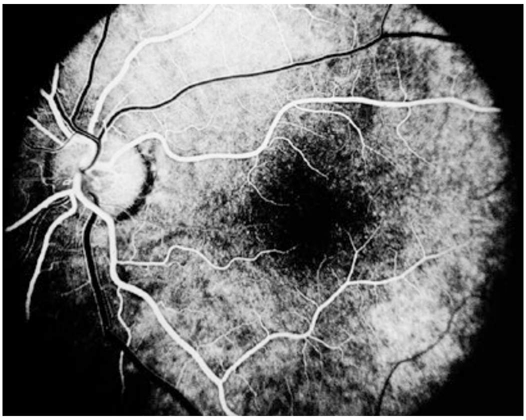


Fig. 20.6 Venous phase; note laminar flow along the venous margins

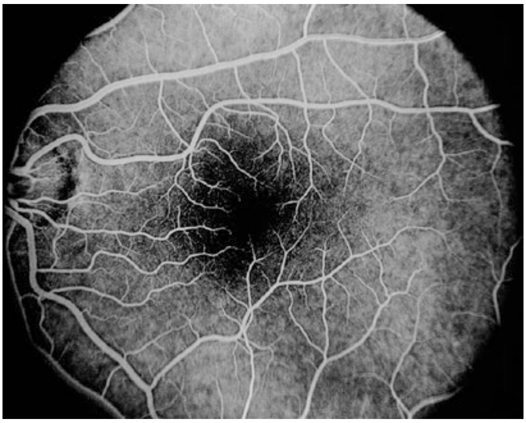


Fig. 20.7 Full arterial venous filling; note avascular zone in the fovea

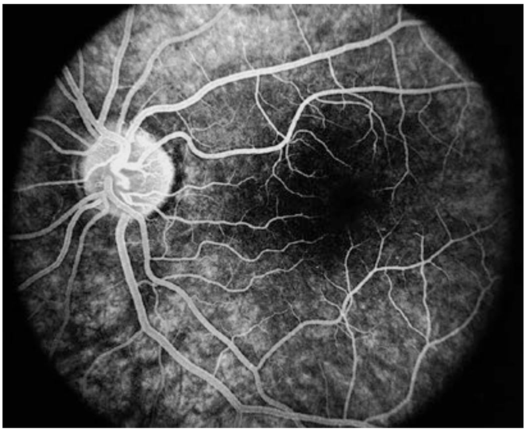


Fig. 20.8 Recirculation of dye; choroidal vessels appear dark against a light background as they are porous, so the dye moves into the extracellular spaces around the vessels

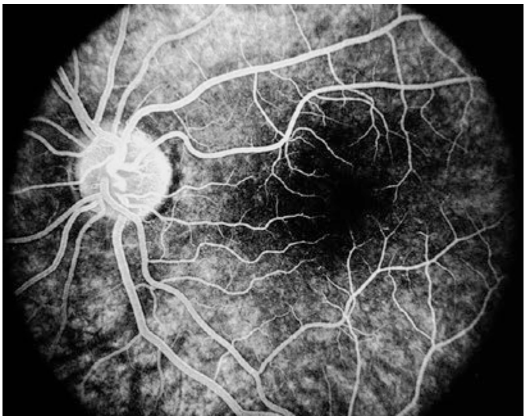


Fig. 20.9 Late phase indicating general fading of the dye as it is removed from the blood

filters all light except 480 nm, which stimulates the dye visible in the retina to a higher energy state. The light reflected back from the retina passes through a barrier filter that eliminates all wavelengths except 525 nm, allowing only the passage of the excited fluorescence. Since the emission of the excited fluorescein dye becomes the sole light source in the images, a clearer view of the retina is often achieved, as any reflected light such as from lens or vitreous opacities (which may have obscured the view during color photography) is reduced or eliminated.

A later variation of ophthalmic angiography was the introduction of indocyanine green angiography (ICGA), which fluoresces in the near-infrared range of 790–805 nm (Figs. 20.25 and 20.26). The molecules of ICG dye bind to the protein in the blood, so they are unable to pass through the fenestrations in the choroidal vasculature as fluorescein dye does. This inability to escape the choroidal vessels allows the ICG to provide details of potential choroidal feeder vessels, such as in choroidal neovascularization (CNV).


Fig. 20.10 Canon CX-1 fundus camera, a non-mydriatic camera with fluorescein capabilities (Courtesy of Canon USA, Inc.)

20.2 Equipment Selection

When making equipment selections, consider what is to be accomplished with the instrument. If the purpose is to provide screening images of undilated patients, such as in telemedicine applications, a non-mydriatic camera can be used. Non-mydriatic cameras (Figs. 20.10 and 20.11) allow photography of the retina without using medication to dilate the patient's eyes. The photography is performed in a dark room to allow the patient's pupils to dilate through normal dark adaptation. In bright light, the pupils constrict, much like the aperture in a camera lens, to reduce the amount of light reaching the retina. In dim or dark conditions, the pupils will naturally dilate to allow more light into the eye. Non-mydriatic cameras take advantage of this behavior by avoiding stimulation of the eye with visible light. After a few minutes in a darkened room, the patient's pupils will dilate and allow a picture to be taken. The cameras utilize infrared wavelengths for viewing and focusing which are undetectable to the human retina; the patient's pupil does not constrict in response. When the flash is fired to capture the image, the pupil will


Fig. 20.11 Non-mydriatic image taken with Canon CX-1 (Courtesy of Canon USA, Inc.)

normally constrict, so the ability to take another photo is dependent upon how long it takes the pupils to re-dilate. This can take anywhere from 30 s to a few minutes. If the decision is made to purchase a non-mydriatic camera, it will also be capable of photography on dilated patients. However, if fluorescein angiography is likely to be performed, that would be an option rather than a typically included feature.

If patients will routinely be dilated, a fully mydriatic camera will be a better choice. This requires the patient to be dilated with drops, usually a combination of phenylephrine hydrochloride or cyclopentolate and tropicamide. Prior to dilation, a slit lamp exam should be performed by a physician or qualified technician to check the anterior chamber angle depth of the eye. This is so as not to dilate anyone with anatomically narrow angles, which may cause an extreme rise in intraocular pressure, resulting in an acute angle closure glaucoma attack. The ophthalmologist should have a protocol regarding patient dilation. For administered procedures such as fluorescein angiography, patient-informed consent should be obtained, a sample of which is below (Fig. 20.12).

20.3 The Digital Age

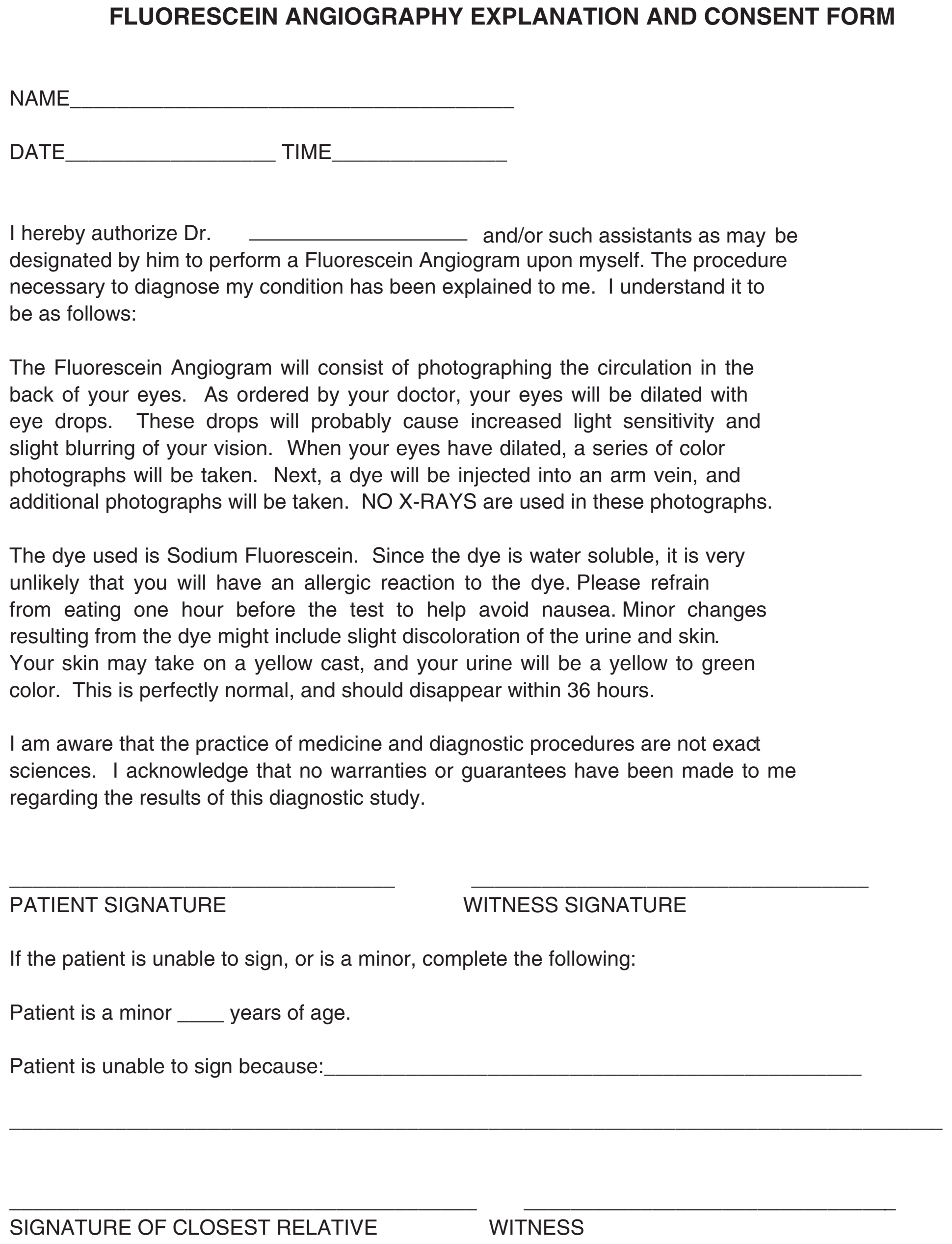
When the digital age brought us instruments producing the quality of film with instant results, the darkroom went by the wayside. The days of "stat" processing have passed. Several manufacturers produce digital cameras that may be attached to formerly film-based instruments, allowing upgrades without the expense of an entire new camera system. If upgrading from a film camera (Fig. 20.13), consider the integration of any capture software with any Electronic Medical Record (EMR) system which may be used in the clinic or office. If using a standalone capture station, have at least one review station set up outside the photography room, so patient flow is not disrupted while waiting for someone to review images. This is vital in a busy practice. Other considerations are the need for prints and the ability to e-mail or otherwise transfer results to referring physicians, which will comply with the Health Insurance Portability and Accountability Act (HIPAA).

Additional advantages of digital imaging are a much shorter learning curve when starting out in the field, as feedback is immediate, allowing the correction of exposure, focus, and field of view while capturing images. Since most systems utilize a monitor or screen, an instructor can provide feedback during a capture session. Many of the newer instruments have done away with the optical viewfinder in favor of screens and monitors. This has also helped resolve problems of accommodation induced by the operator when trying to focus the image. The optical eyepieces use a reticle within the optics making it necessary to adjust for the operator's induced accommodation in order to produce a sharply focused image.

20.4 Corneal Spectral Microscopy

Corneal spectral microscopes (CSM) image corneal cells. The cornea is the transparent front surface of the eye which provides the highest curvature and refractive ability in the eye. Age, corrective refractive surgery such as Lasik, and cataract surgery all compromise the corneal endothelial cells. These cells do not regenerate, so when the cell concentration becomes too low due to age, disease, trauma, or surgery, the cornea becomes compromised, potentially necessitating a corneal transplant. The CSM allows the photography of sections of the cornea whereby an accurate count of corneal endothelial cells may be made, and a determination as to the cornea's viability assessed. This may result, for example, in the decision to forego cataract surgery, as the loss of corneal endothelial cells may compromise the cornea leading to visual loss even greater than the existing cataract.

The Nidek CEM-530 (Fig. 20.14) is an example of a CSM. Features of modern CSMs include auto analysis for rapid and accurate cell counts without the labor-intensive process of previous film-based instruments, which required hand cell counting on standardized photographic prints. Some models of CSMs have wide angle "panoramic" imaging capabilities (Fig. 20.15), for a larger area of analysis.



FLUORESCEIN ANGIOGRAPHY EXPLANATION AND CONSENT FORM

NAME____

DATE___________________ TIME________________

I hereby authorize Dr. ____________________ and/or such assistants as may be designated by him to perform a Fluorescein Angiogram upon myself. The procedure necessary to diagnose my condition has been explained to me. I understand it to be as follows:

The Fluorescein Angiogram will consist of photographing the circulation in the back of your eyes. As ordered by your doctor, your eyes will be dilated with eye drops. These drops will probably cause increased light sensitivity and slight blurring of your vision. When your eyes have dilated, a series of color photographs will be taken. Next, a dye will be injected into an arm vein, and additional photographs will be taken. NO X-RAYS are used in these photographs.

The dye used is Sodium Fluorescein. Since the dye is water soluble, it is very unlikely that you will have an allergic reaction to the dye. Please refrain from eating one hour before the test to help avoid nausea. Minor changes resulting from the dye might include slight discoloration of the urine and skin. Your skin may take on a yellow cast, and your urine will be a yellow to green color. This is perfectly normal, and should disappear within 36 hours.

I am aware that the practice of medicine and diagnostic procedures are not exact sciences. I acknowledge that no warranties or guarantees have been made to me regarding the results of this diagnostic study.

___________________________________ ____________________________________

PATIENT SIGNATURE WITNESS SIGNATURE

If the patient is unable to sign, or is a minor, complete the following:

Patient is a minor ____ years of age.

Patient is unable to sign because:____

____

____ __________________________________

SIGNATURE OF CLOSEST RELATIVE WITNESS

Fig. 20.12 Sample fluorescein angiogram consent form

20.5 Photo Slit Lamp Biomicrography

The slit lamp biomicroscope is one of the more common instruments used in the examination of the eye. The non-photographic models are common to nearly all ophthalmology and optometric practices and are used routinely across eye care in evaluating eye health. An example of the photographic version of this instrument is the Haag-Streit BX900 photo slit lamp with still and video capture capabilities (Fig. 20.16).

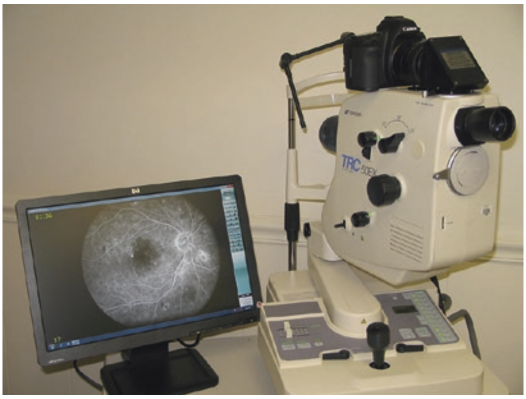


Fig. 20.13 Fundus Photo, LLC digital system with Canon EOS 60D added to Topcon TRC 50EX fundus camera. (Image courtesy of Michael Gerkovich at Fundus Photo, LLC St. Louis, MO)

Fig. 20.14 Nidek CSM-530 corneal spectral microscope (Courtesy of Nidek, Inc.)

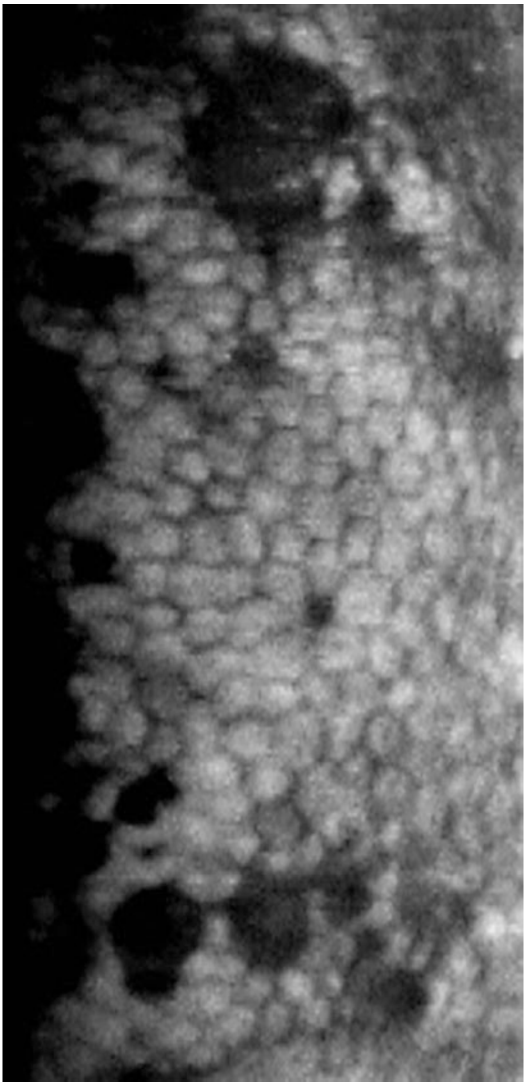


Fig. 20.15 Panoramic image of the corneal endothelium (Courtesy of Nidek, Inc.)

The live capture mode is especially helpful as you see what the camera sees. It is used to evaluate the anterior structures of the eye, especially the cornea, sclera, lens, and angles of the eye. With auxiliary lenses, the vitreous, posterior pole, and gonio views are visible. The magnification range is 10x to 40x depending on the eye piece. This instrument is binocular, giving excellent stereo views of the structures of the eye. The slit lamp has two independently controlled light sources. The slit beam (hence, the name of the instrument) is adjustable from a circle to a narrow slit and can be rotated through 90°. The second light source is a fill light for overall illumination, which helps with orientation as to which part of the eye is being viewed (Fig. 20.17). When a photographic capture system is added to the slit lamp, records of the structures may be made. The photo slit lamp is considered one of the more challenging instruments in ophthalmic photography as it utilizes the two light

Fig. 20.16 Haag-Streit BX900 photo slit lamp (Courtesy of Haag-Streit USA, Inc.)

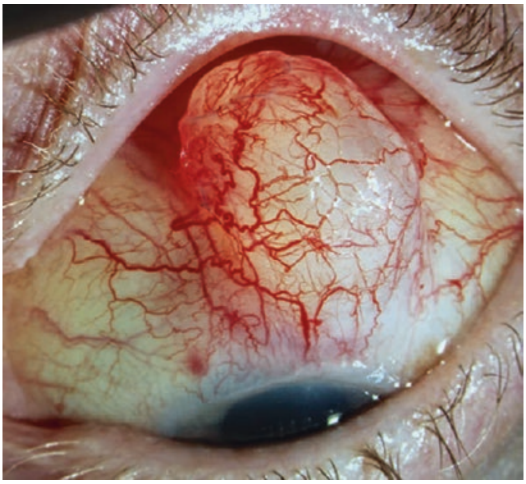


Fig. 20.17 Photo slit lamp of an encapsulated filtering bleb image by Sergey Vostrukhin (Courtesy of Haag-Streit USA, Inc.)

sources. In a true photo slit lamp, a flash tube is incorporated into the light sources, which must be balanced for a good exposure, f stops for extended depth of field, and variable magnification. The photo slit lamp is also capable of performing iris angiography with the addition of the fluorescein barrier filter. Most slit lamps already possess the equivalent of the fluorescein exciter filter, as it is common to use fluorescein staining for intraocular pressure checks with the tonometer. Fluorescein staining is also used to show corneal damage, as the disturbed epithelium will retain the dye showing bright staining on examination and photography.

20.6 Optical Coherence Tomography

Optical coherence tomography (OCT) was first developed in 1991 (Fig. 20.18). It works much like a Michelson interferometer where a beam splitter divides the light source into two beams, one of which is directed at the tissue sample (the eye) while the second beam is directed at a reference mirror. When the light reflected back from the tissue sample is recombined with the reference beam,

Fig. 20.18 Cirrus 5000 OCT (Courtesy of ZEISS)

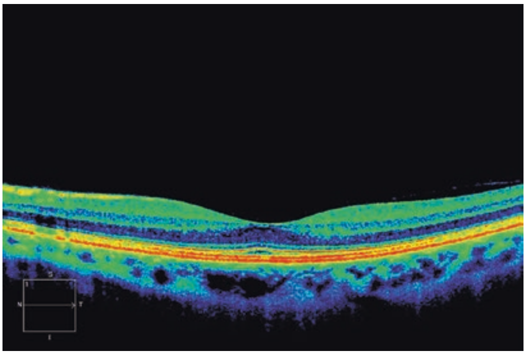


Fig. 20.19 OCT of a normal retina; the central depression is the foveal area

this produces an interference pattern (image) of the tissue sample. OCT is a noninvasive procedure using laser light to perform a raster line scan of the retina, building an image of tissue densities as it progresses (Fig. 20.19). The OCT is an excellent device for tracking optic nerve damage due to high intraocular pressure, as in glaucoma, or the inability of the eye to withstand normal pressures; macular edema from diabetes; cystoid macular edema; epiretinal membranes; macular holes; or any other disruptions to the thickness or integrity of the macular tissue. In many cases, patients are followed with OCT for these problems and are treated based on the OCT information. In the past, frequent fluorescein angiography was performed to make the necessary determination as to the treatment.

OCT angiography (OCTA) is one of the newest imaging technologies in ophthalmic imaging. This advancement in OCT imaging uses multiple raster passes over the same area of the retina to image motion-induced changes in blood vessels created from the circulatory process (Fig. 20.20). This allows the imaging of viable blood vessels without the use of dyes. A limitation of this technology is its inability to show areas of pooling or staining which would be visible with conventional fluorescein angiography.

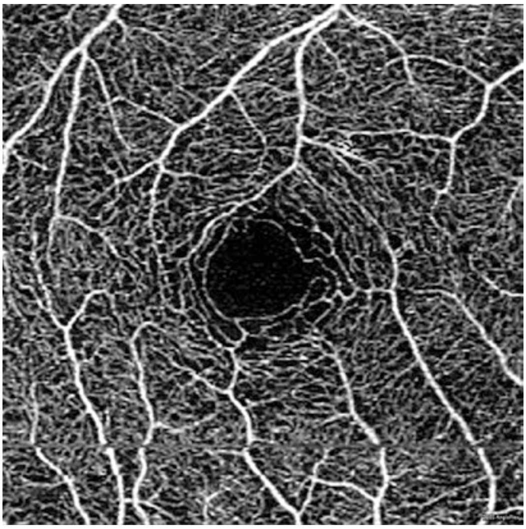


Fig. 20.20 OCTA captured with the Zeiss Cirrus 5000 (Courtesy of ZEISS)

20.7 Autofluorescence

Autofluorescence (AF) or fundus autofluorescence (FAF) (Fig. 20.21) uses light to stimulate potential fluorescent structures of the retina, most notably lipofuscin accumulations and the state of the retinal pigment epithelium (RPE). The accumulation of lipofuscin in the retina is a normal aging process, but certain diseases and medications may cause an acceleration of this accumulation or abnormal patterns of accumulation giving insight into potential disease processes or medication-induced retinal toxicity.

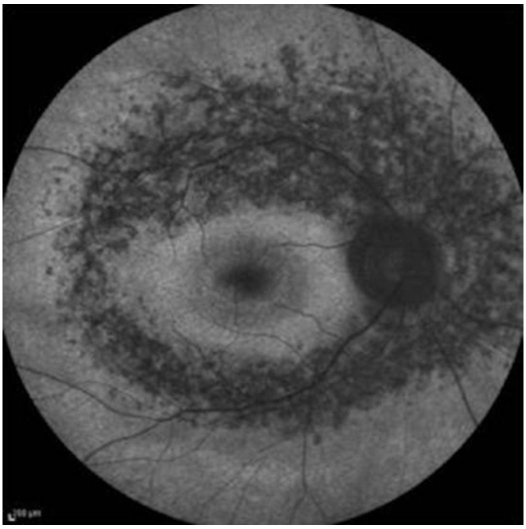


Fig. 20.21 Autofluorescence produced by lipofuscin in the macula. (Image courtesy of ZEISS)

20.8 Scanning Laser Ophthalmoscope

The scanning laser ophthalmoscope (SLO) uses light-emitting diode (LED) lasers to produce a raster scan pattern to build an image of the eye much like the OCT technology. While capable of multiple wavelengths and using red, green, and blue to build a color image, they do not produce true color images of the retina as are achieved with conventional flashtube-based instruments. Advantages of the SLO in image capture are its ability for image clarity through cataracts and other media opacities and lower luminescence providing greater patient comfort.

A variation of the SLO is the confocal scanning laser ophthalmoscope (cOCT) which adds a pinhole to the optical pathway to block extraneous light and produces an image with higher contrast and focus than the original SLO instruments.

Fourier or spectral domain optical coherence tomography (SD-OCT) is an advancement of the original OCT. SD-OCT uses a near-infrared diode light source with a center wavelength around the 840 nm range. The primary improvement over the initial OCT is the faster scan time with higher resolution. This reduces artifacts induced by movement of the patient's eye or head. With the higher-resolution and faster scans, more data are captured, which allows the building of a 3D model or cube of the eye. Rotation of this cube gives various views of the eye with sectioning at any desired angle. Most SD-OCT scans may be acquired without patient dilation in a darkened room. The instruments are usually set with internal fixation targets for the patient helping to automate scans of the macula and optic nerve. When scans outside of the preprogrammed areas are required, the fixation target and scan area may be independently adjusted allowing more peripheral views to be captured. If necessary, an external fixation target may be utilized for patients with monocular vision. Most of the currently available models are capable of anterior segment imaging which allow measurements of corneal thickness and the anterior chamber angle of the eye which previously required the application of a gonio lens and the use of a slit lamp to visualize.

Swept source optical coherence tomography (SS-OCT) is the latest advancement to OCT technologies. The SS-OCT uses a tunable swept laser with a center wavelength around 1050 nm. This longer wavelength allows greater penetration through the retinal pigment epithelium (RPE) and greater signal detection from deeper retinal tissue. Since the longer wavelength is less harmful to the eye, higher intensity may be used in the scanning process.

Multimode imaging instrumentation gives the option of purchasing only the testing modalities currently needed and, in some cases, allows later expansion of new image acquisition techniques as they become available. The Heidelberg Engineering Spectralis (Figs. 20.22, 20.23, 20.24, 20.25, 20.26, 20.27, and 20.28) shows a comparison of the various capture modalities the instrument is capable of. The Spectralis uses a cSLO technology to build the images. By adjusting the wavelengths of the lasers, different layers of the retina and choroid may be better imaged. With the ability to change the objective lens, the field of view may be captured from 15° to the widefield 120° and finally the ultra-widefield imaging module with a field of view encompassing up to 150°. Other features include an anterior segment module allowing high-resolution imaging of the cornea, sclera, and angles of the anterior chamber. The BluePeak module (for autofluorescence) helps map lipofuscin, which indicates macular degeneration. The OCT module incorporates high speed capture with an optional glaucoma module and OCT angiography capabilities.

Fig. 20.22 Heidelberg Spectralis. (Image courtesy of Heidelberg Engineering)

Fig. 20.23 Spectralis MultiColor 55° healthy retina. (Image courtesy of Heidelberg Engineering)

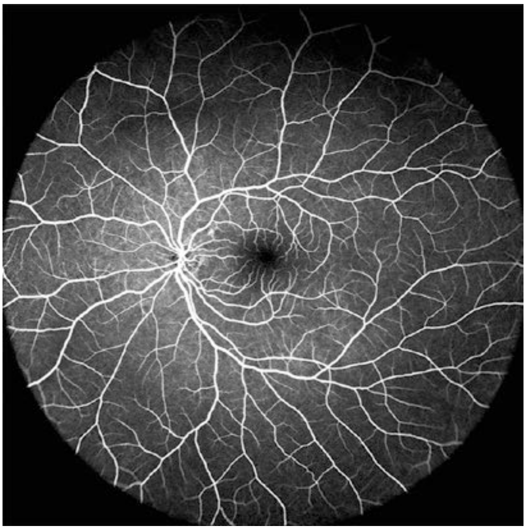


Fig. 20.24 Spectralis Ultra-widefield FA normal eye. (Image courtesy of Heidelberg Engineering)

20.9 Ultra-Widefield Imaging

Ultra-widefield imaging may provide an image field up to 200°, as in the Optos p200MA (Figs. 20.29 and 20.30).

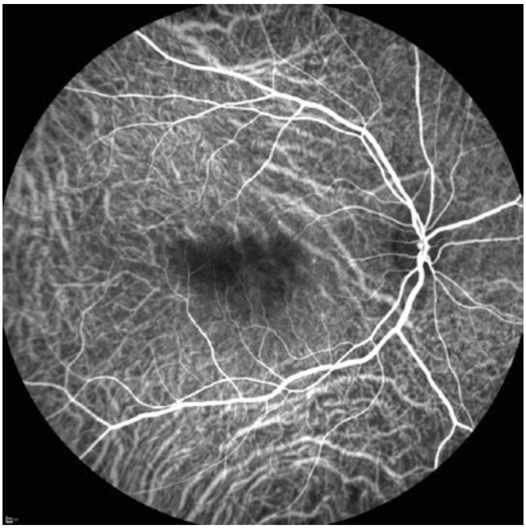


Fig. 20.25 Spectralis Widefield ICGA healthy eye. Image courtesy of Heidelberg Engineering

The Optos uses multiple scanning laser wavelengths of green at 532 nm, red at 635 nm, blue at 488 nm, and infrared at 802 nm. This allows visual separation of the inner and outer retina. The green wavelengths provide imaging of the retinal blood vessels as well as autofluorescence, while the red wavelengths image the deeper choroidal vessels. The blue wavelength is for fluorescein angiography, and the infrared provides ICG capability. The ultra-wide field of view extends beyond the normal field of view of more traditional retinal cameras and gives insight into peripheral retinal circulation and potential pathology which might otherwise go unnoticed. Diseases such as retinopathy of prematurity, sickle cell anemia, retinal detachments, peripheral diabetic changes, and tumors are examples of such disease conditions.

The Phoenix ICON retinal imaging platform (Fig. 20.31) is primarily a contact instrument (the objective lens is in contact with the cornea for ideal imaging). This provides access to patients under anesthesia, bedridden patients, pediatric patients, or those otherwise unable to sit up at traditional imaging equipment. The optical design

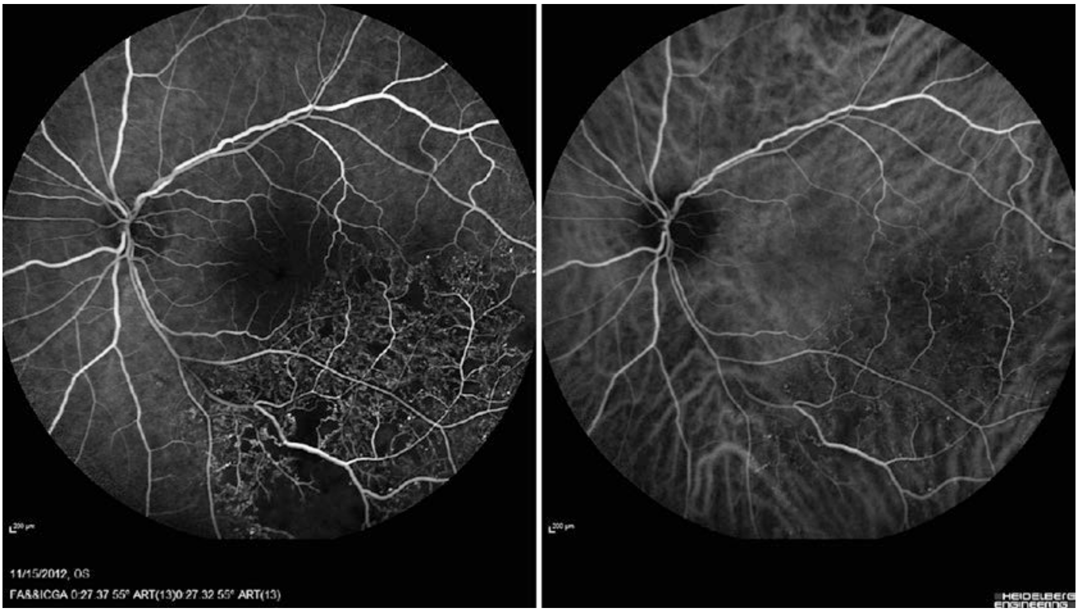


Fig. 20.26 Spectralis Simultaneous FA left image and ICGA right image (Courtesy of Heidelberg Engineering)

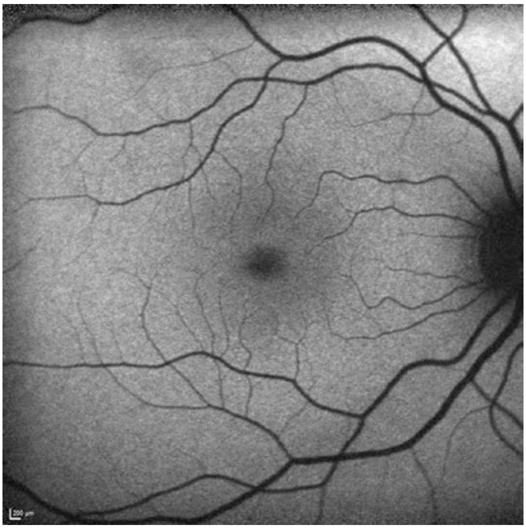


Fig. 20.27 Spectralis BluePeak autofluorescence normal eye. (Image courtesy of Heidelberg Engineering)

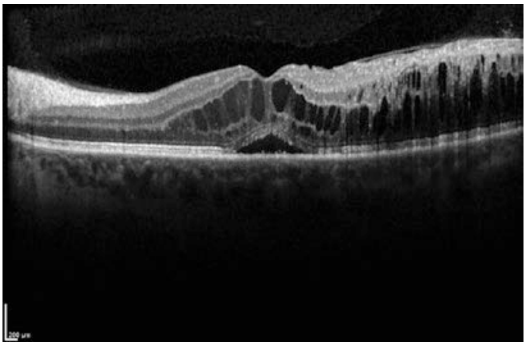


Fig. 20.28 Spectralis OCT showing macular edema. (Image courtesy of Heidelberg Engineering)

provides a high-contrast, widefield image even on darkly pigmented retinas (Fig. 20.32).

20.10 Telemedicine

Fig. 20.29 Optos P200C imaging system. (Image courtesy of Optos)

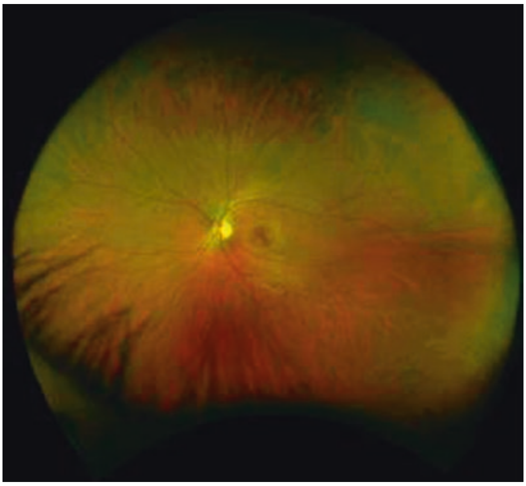


Fig. 20.30 Normal retina imaged with Optos P200c. (Image courtesy of Optos)

Telemedicine is a growing area of medicine, and ophthalmology is on the forefront of this field. Self-contained instruments, capable of “in-the-field” screening, bring ophthalmic medical care to otherwise underserved communities and remote areas. These instruments should be small, portable, and, when possible, battery operated. The iExaminer iPhone adapter from Welch Allyn

Fig. 20.31 ICON camera with insert of handheld optical head. (Images courtesy of Phoenix Technology Group)

Fig. 20.32 100° view captured with the Phoenix ICON. (Image courtesy of Phoenix Technology Group)

(Fig. 20.33) is one of the simplest and most portable of these devices and provides a field of view of 25° (Fig. 20.34). For greater screening purposes, instruments such as the Nexy provide a wider field of view and good portability (Figs. 20.35 and 20.36). In most cases, images may be captured and stored in the instruments for later upload when an Internet connection is unavailable.

Fig. 20.33 iExaminer from Welch Allyn. (Image courtesy of the author)

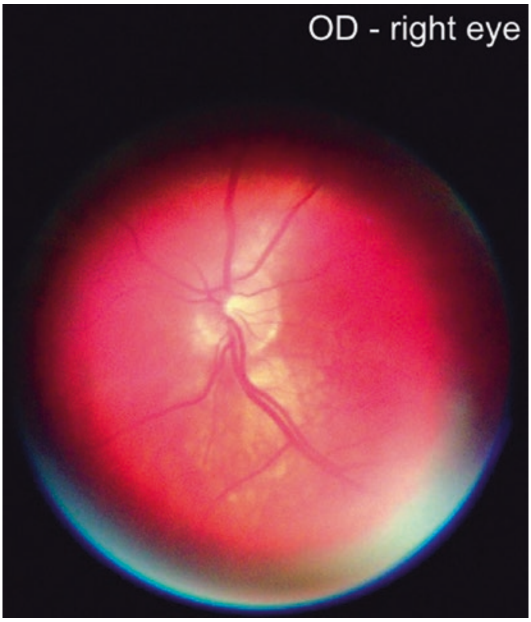


Fig. 20.34 Image with iExaminer from Welch Allyn. (Image courtesy of the author)

Fig. 20.35 Nexy with tablet. (Image courtesy of Next Sight Srl (Padova, Italy))

Fig. 20.36 Auto photomontage of the right eye created with Nexy (Courtesy of Next Sight Srl (Padova, Italy))

20.11 Summary

Ophthalmic photography and imaging has advanced tremendously in both image quality and diagnostic value. While the early advancements often took decades or longer to bear fruit, today's technology moves at a previously unimagined pace. New diagnostic approaches, imaging techniques, and refinements move so quickly as to be difficult to keep up with. Artificial intelligence (AI) is being tested for applications in image screening of potential diabetics. This is just the early stage and will lead to greater automation in equipment, examination, decision-making, and patient treatments. Even with these advancements in technology, the person behind the instrument should have a firm understanding and knowledge of the anatomy and pathology of the eye and possess skill with the instrument when the need for troubleshooting arises. While the complexity of the equipment operation may become more automated, oftentimes, situations arise when operator intervention is required to produce a quality image in a difficult situation. While some of the instruments boast fully automated capture, eliciting the necessary positioning, cooperation, informed consent, and capturing, the proper images fall to the operator. Even with limited knowledge of potential pathology, a clear understanding of what constitutes "normal" is vital and will provide the opportunity to image anything which does not fall into the normal range even when it wasn't indicated on the initial exam.

20.12 The Ophthalmic Photographers' Society

Founded in 1969, the Ophthalmic Photographers' Society has grown into an international organization which provides education and certification in ophthalmic imaging. Certifications as a retinal angiographer (CRA) and optical coherence tomography certification (OCT-C) are administered through the OPS board of certification.

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Further Reading

Resources

American Academy of Ophthalmology. https://www.aao.org/
Joint Commission on Allied Health Personnel in Ophthalmology. http://www.jcahpo.org/
Ophthalmic Photographers' Society. https://www.opsweb.org/

Imaging Equipment Manufacturers

Canon Medical Systems. https://www.usa.canon.com/internet/portal/us/home/products/groups/eyecare/
Carl Zeiss Meditec, Inc. https://www.zeiss.com/meditec/us/home.html
CenterVue. https://www.centervue.cocm/company/
Forus Health, Inc. http://forushealth.com/forus/usa/classic.html
Fundus Photo, LLC. http://fundusphoto.com/
Haag-Streit, USA. https://www.haag-streit.com/haag-streit-usa/
Heidelberg Engineering, Inc. https://www.heidelbergengineering.com/us/
IRIS (Intelligent Retinal Imaging Systems). http://www.retinalscreenings.com/
Konan Medical. https://konanmedical.com/
Kowa. https://ophthalmic.kowa-usa.com/
Leica Microsystems. https://www.leica-microsystems.com/
Nidek, Inc. http://usa.nidek.com/
Optos, Inc. https://www.optos.com/
Optovue, Inc. https://www.optovue.com/
Phoenix Technology Group. http://phoenix-clinical.com/
Topcon America Corporation. http://www.topconmedical.com/
TTI Medical. http://ttimedical.com/
Quantel Medical. https://www.quantel-medical.com/
Vision Care Academy. https://vision-care.academy/
Volk Optical, Inc. https://volk.com/

Clinical Dental Photography

21

Irfan Ahmad

Contents

21.1 Introduction

Digital dental photography consists of extra-oral, intra-oral, portraiture and bench images. Before embarking on a photographic session, it is important to decide on the intended use of the images. Dental photography can simply be photodocumentation for facilitating a specific treatment or used for marketing, teaching or artistic endeavours. Clinical dental photography varies from promotional or artistic photography. The former depicts clinical reality, while the latter is seductive and alluring for promotional purposes. The remit of this chapter is to focus on clinical photography that is essential for several dental disciplines.

The most frequently photographed dental images are intra-oral and extra-oral, which include the surrounding lips and soft tissues. Also, clinical portraits are often necessary for several disciples including orthodontics and cranio-maxillo-facial and cosmetic procedures. The array of uses include photodocumentation (dento-legal, treatment planning/monitoring),

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P. Pasquali (ed.), *Photography in Clinical Medicine*, https://doi.org/10.1007/978-3-030-24544-3_21

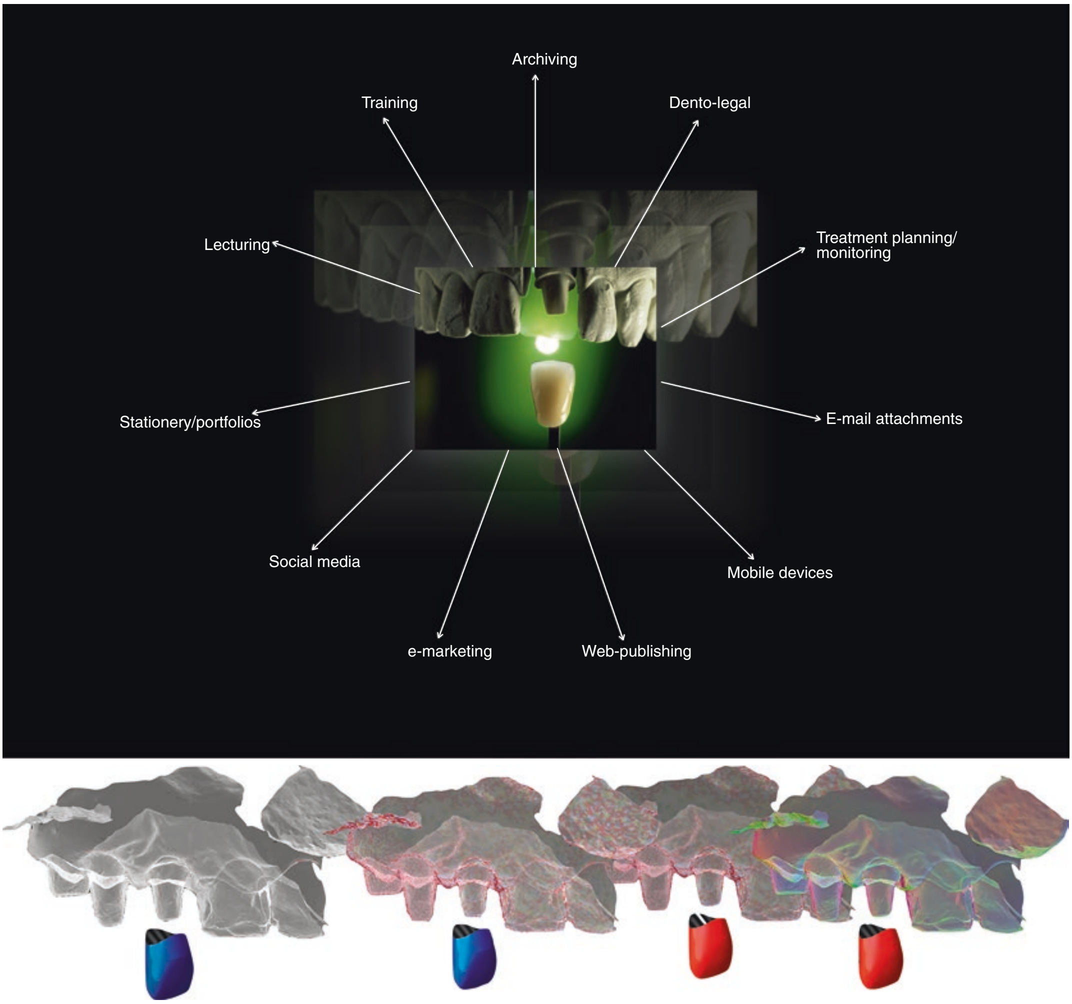


Fig. 21.1 Some uses of dental images

communication (e-mail attachments, sharing pictures on mobile devices), marketing (web publishing, e-marketing, social media, office stationery, treatment portfolios) and education (lecturing, training) (Fig. 21.1).

Nowadays, nearly all photography is digitally based, having superseded analogue film photography that dominated the last century. The digital process is succinctly summarized by the CPD triad, capture, processing and display. The capture stage is accomplished with a camera having a digital sensor, processing by imaging software and display by a monitor, projector or printed media.

21.2 The Photographic Equipment

The sequence of CPD starts by acquiring a digital representation of an object or subject using an armamentarium of photographic equipment.

21.2.1 Cameras

The market is awash with cameras offering countless functions, some superfluous and others essential, and deciphering which are useful or redundant is a challenging and annoying endeavour [1]. Many camera features that are supposedly added to make life easier often end up as frustrating nuisances, and wading through never-ending cascading menus requires aptitude and endurance. This is probably the biggest turn-off for potential purchasers, who are bombarded with technical jargon, acronyms they do not understand and features they are unable to comprehend. Therefore, it is important to ignore manufacturers' hype and concentrate on salient specifications. The type of camera systems available is a minefield, such as point-and-shoot, compact, CCS (compact camera systems), EVIL (electronic viewfinder, interchangeable lens), MILC (mirrorless interchangeable-lens compacts), rangefinders, dSLR (digital single-lens reflex) and, of course, not forgetting the smartphone (cellphone) varieties.

In order to satisfy the requirements of dental photography and produce images that are rich in detail, vibrancy, nuances of colour, texture and form, conveying emotions, feelings and unparalleled quality, the only choice at present is a dSLR [2]. While other category of cameras can be tailored or adapted for dental use, the task is onerous and probably not worth the frustration for the small cost saving that is often elusive. Having established that a dSLR is the ideal camera for dental applications, the next question is 'which proprietary brand to choose?' [3]. The advice in this chapter concentrates on generic photographic equipment, which fulfils basic requirements for dental applications. Also, with technological advances, newer products are perpetually being introduced, which readily become obsolete in a short space of time. As a general guide, mid-range dSLRs from any major brands are almost identical in terms of features and the image quality they offer.

A dSLR consists of a body containing the mechanics and electronics or brain of the camera. A camera body usually comes as a kit with a lens and other basic accessories. However, most lens that form a kit are often unsuitable for dental applications, and if possible, it is advisable to purchase the body alone or exchange the accompanying lens for one that is more suited for dental use.

The primary features to look for in a camera body are:

- The physical size of the sensor
- Megapixel count
- Colour depth
- Numerical white balance input
- External flash synchronization via a hot shoe with TTL (through-the-lens) metering
- Switchable manual focusing
- Sensor speed or ISO range
- Remote shutter release
- Tripod thread(s)
- Ease of sensor cleaning

The secondary features include:

- Exposure modes and metering
- Shutter speeds
- Sequential frames per second
- Colour space
- Dust and water spray sealing
- Anti-fingerprint and anti-scratch coating of the LCD (liquid crystal display) touchscreen
- RAW file formats
- Video capability
- GPS (global positioning system)
- Wi-Fi
- Storage media
- Interface for data transfer
- Built-in photo-editing software
- Build quality
- Size
- Weight
- The price

While there is no compromise of the mandatory primary features, the secondary features are desirable, but not necessary. Although the list of primary or secondary specifications may seem endless, there is no need to fret since most dSLRs have these features as standard. But, like anything in this world, you get what you pay for; the higher the specifications, the higher the price. All major camera brands, such as Canon, Nikon, Fujifilm, Sony, Panasonic (Lumix), Pentax and Olympus, offer mid-range or semi-professional dSLRs suitable for dental requirements for around US$ 500 at current prices. Table 21.1 itemizes the specifications for choosing a camera.

Table 21.1 Specifications of a dSLR camera for dental photography

Specification	Must have	Wish list
Sensor size	Minimum APS-C	Full-frame (36 mm × 24 mm), matching the focal length of lens
Pixel count in MP (megapixels)	Minimum 18 MP (depending on physical size [dimensions] of sensor)	>18 MP (depending on physical size [dimensions] of sensor)
No anti-alias filter	Desirable	Mandatory
ISO range	Minimum 100–200: any maximum	
Sensor cleaning	Ease of manual sensor cleaning	Automatic, built-in sensor cleaning mechanism
Colour depth	8 bit/colour (channel)	16 bit/colour (channel)
Dynamic range (human eye = 24 *f* stops)	Minimum 6 *f* stops	≥10 *f* stops
White balance	Auto or numerical input [5500 K]	
Focusing	Manual focus capability	
External flash connections	Hot shoe, x-jack	Wireless/via smartphone
Remote shutter release	Wired hand/foot cable release	Wireless/via smartphone
Tripod screw thread	1/4-20 UNC (Unified National Coarse)	1/4-20 UNC or 3/8-16 UNC and a 1/4-20 UNC adapter
Exposure modes	Aperture priority and manual	
Metering modes	Centre weighted, multi-zone, spot	
Shutter type	Focal plane	Built-in lens
Shutter drives	Single and multiple	
Shutter flash synchronization speed	1/125 s or 1/250 s	Any shutter speed possible with built-in lens shutters
Colour space	sRGB, Adobe® RGB	
File format	Proprietary RAW or Adobe® DNG (digital negative graphic), JPEG	
Storage	UHS I (30 MB/s writing speed) SD card	UHS II (100 MB/s writing speed) SD card or internal RAM storage
Data transfer	USB 3 or greater, audio in/out jacks, HDMI	Wi-Fi
Video recording capability	HD 1080p (progressive) to 60 fps (frames per second)	>4K (similar quality to conventional cine film)
Location		GPS (global positioning system)
LCD (liquid crystal display)	Touchscreen	Anti-fingerprint and anti-scratch coating
Camera protection		Dust and water spray sealing
Build quality, weight, size	Portable, light-weight, die-cast aluminium	Milled aluminium

21.2.2 Lenses

The technical requirements of a lens for dental photography are that it serves a dual-purpose, first for portraiture and second for close-up or macrophotography. The ideal lens for portraiture is around 100 mm focal length and for macrophotography is a macro facility for achieving a 1:1 or 1:2 magnification. A 1:1 magnification ratio means that the image recorded on the sensor is the same size as the object, while a 1:2 magnification means that the captured image is half the size of the object. Macro lenses are either available as fixed focal lengths, called prime lenses, or zooms with variable focal lengths. It is recommended to use prime lenses, rather than zooms, which are usually impractical for dental photography. Furthermore, fixed focal length macro lenses greater or less than 100 mm are unsuitable for the following reasons. To achieve a 1:1 magnification with a 50 mm macro lens requires moving the camera extremely close to the subject, which may be intimidating for the patient. In addition, at this close distance, the cheeks and lips block the flash lights illuminating the oral cavity. Another problem with a 50 mm lens is that portraits at close distances result in spherical distortion, making the nose or other prominent parts of facial features appear larger and less flattering. Conversely, macro lenses greater than 100 mm, say 200 mm, require greater distances for obtaining a 1:1 magnification. This is also a hindrance since brighter lights are necessary to correctly illuminate the subject that is now further away, plus the physical size and weight of these lenses are inconvenient for hand-held cameras. Many contemporary lenses offer image stabilization for preventing blurred images. However, this feature is superfluous for dental photography since the high flash synchronization shutter speeds (1/125 s or 1/250 s) and the fraction of a second flash burst 'freeze' the subject, obviating the need for image stabilization. It is important to realize that image stabilization is different from focusing; the former compensates for involuntary micro-movements referred to as 'camera shake' (for hand-held cameras), while the latter is concerned with focusing a sharp image onto the sensor depending on the distance of the object from the camera.

Most dSLRs are sold with general-purpose lenses, usually variable zooms, satisfying broad photographic genres such as family shots, portraiture, landscape, sports, wildlife, etc. However, these lenses are a 'jack of all trades' and 'masters of none'. They offer acceptable resolving power, but not superlative resolution.

The lens is a crucial factor for determining the image quality, and its resolving power should match or be greater than the size of the pixels, which vary from 5 to 12 μm. An array of lenses are available, either the same brand as the camera, third-party or from different brands using appropriate adapters. The same brand lenses have the advantage that they seamlessly synchronize or integrate with the camera electronics and can be updated with the latest firmware, but are usually more expensive. The market is inundated with third-party lenses, some inferior and others offering even better resolution than same brand lenses. Lastly, lenses from old 35 mm film cameras can easily be fitted with relatively inexpensive adapters to almost any camera. These offer excellent optics since they are usually constructed of glass elements but are heavier, whereas newer versions are often made of plastic elements, with reduced acuity, but are much lighter in weight. Some high-end macro lenses have the prefix 'Apo' and 'ASPH', which eliminate apochromatic and aspherical aberrations, respectively. These optically corrected lenses may be the same brand as the camera or third-party lenses with state-of-the-art optics for exceptional resolution, but come with a hefty price tag, e.g. Carl Zeiss®, Schneider-Kreuznach®, Meyer Optik Görlitz®, Voigtländer® and Leica® to name a few. In addition, a search on e-Bay™ offers many pre-owned high-end lens at a fraction of the new retail price, and with appropriate adapters, e.g. from Fotodiox® or Novoflex®, can be fitted to almost any camera body.

A further issue to contend with is whether the focal length of the lens matches the size of the sensor. The focal length of lenses is usually quoted according to old 35 mm film cameras. If the camera has a full-frame sensor (36 mm × 24 mm), the image seen in the viewfinder will almost be identical to what is recorded on the sensor (crop factor of 1). However, if the size of the sensor is smaller, say APS-C (22.2 mm × 14.8 mm), the lens image circle is greater than the sensor size, and only the central part of the image is recorded on the sensor. For example, with an APS-C sensor, the lens has a crop factor is 1.61 (Fig. 21.2). Also, for smaller sensors found in compact cameras, the crop factor becomes even greater, while for larger sensors in medium format cameras, the crop factor reduces to less than 1. Therefore, it is desirable to have a full-frame sensor so that the focal length of the lens matches the sensor size, but the additional cost of the camera body may be prohibitive. To summarize, the choice of a lens for dental photography is empirical, dictated by personal preferences and cost, which can vary from US$ 600 to UD$ 1000, or more, if image quality is an absolute priority.

21.2.3 Flashes

There are two types of lights required for dental photography: compact and studio flashes [4]. The compact flashes are further sub-divided into ring flash (ring light), compact off-the-camera bilateral (bi-directional or twin light) flashes or a

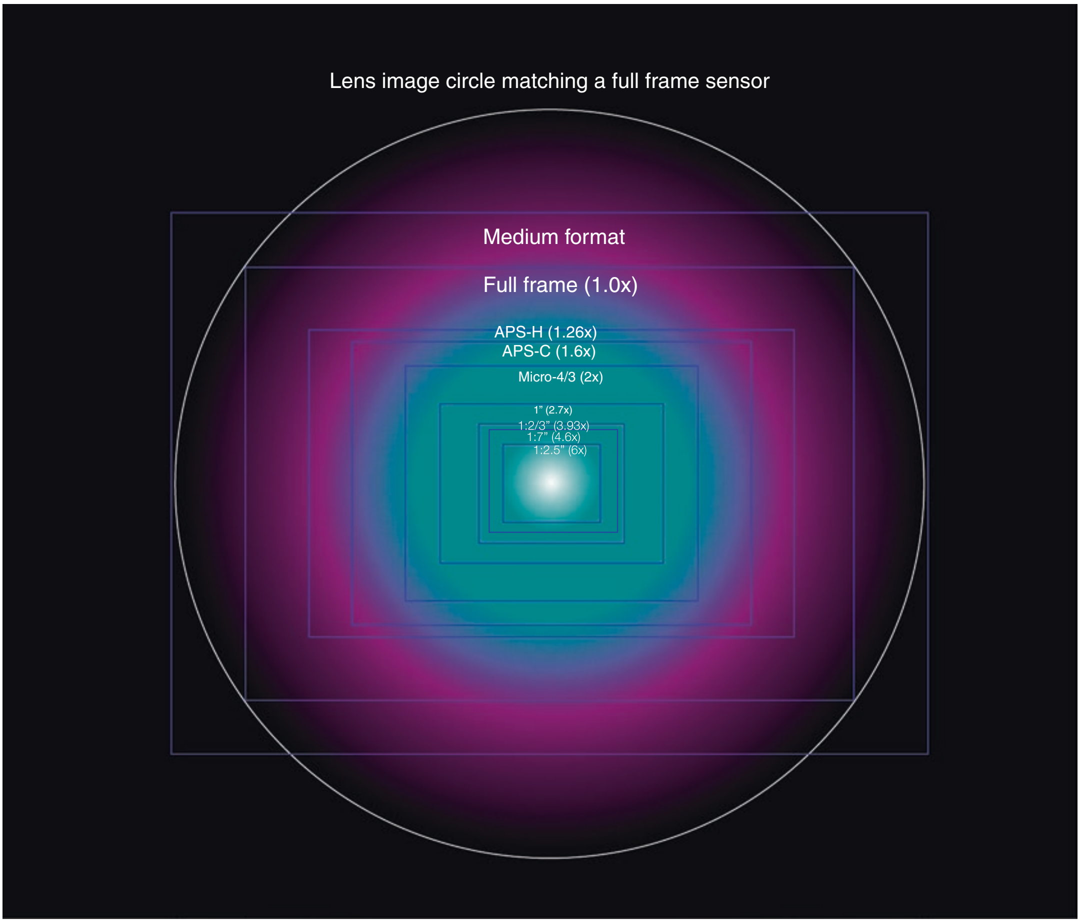


Fig. 21.2 Comparison of digital camera sensor sizes, together with the corresponding crop factor in parenthesis

Fig. 21.3 Ring flash on a dSLR camera system

Fig. 21.4 Bi-lateral twin flashes on a dSLR camera system

single unit consisting of both ring and twin lights (Figs. 21.3 and 21.4). Compact ring flashes attach directly onto the front of the lens, emitting uniform (360°) shadowless illumination, which is ideal for hand-held pictures, especially in the darker posterior regions of the mouth where access for light is restricted by the surrounding cheeks and lips. The price for ring flashes ranges from US$ 100 to US$ 500, depending on the type, make and guide number. The major drawback of ring flashes is that the light is harsh, uniform and characterless. While ideal for photographing posterior teeth, for anterior teeth, this type of illumination produces images that are bland, are boring and lack lustre. For anterior teeth, or for restorations where aesthetics are of paramount concern, ring flashes are not recommended since the uniform burst of light obliterates fine detail, translucency, surface texture, topography and subtle colour transitions and nuances within teeth or artificial restorations.

For portraits, two varieties of studio flashes are available: the monolights, which connect directly to the mains, or the pack and head that require a separate power pack, which are indicated for location shooting. For dental applications, monolights are the most convenient, incorporating integral modelling lights to help position and orientate the flashes before taking a picture. The flash inteansity or output of a flash tube is either measured in watts/second (W/s) or expressed as a guide number (GN), similar to compact flashes, e.g. a 120 W/s flash has a GN of 125 (100 ISO feet) or 38 (100 ISO meter), while a 300 W/s has a GN of 190 (100 ISO feet) or 58 (100 ISO meter). If the flashes are intended only for headshots of a single person, two 120 W/s flashes are sufficient. However, if pictures of small groups, of bigger objects in larger spaces or of creative lighting with light-modifying attachments are required, two or more >300 W/s flashes are recommended. In addition light-modifying attachments are necessary for manipulating light for creative effects, e.g. reflective umbrellas, soft boxes, gels, barn doors, honeycomb grid diffusers, reflectors, Fresnel lenses, etc. A good starting point is using two soft boxes and, once proficient, experimenting with more sophisticated modifiers for conveying ambience and mood.

21.2.4 Other Photographic Equipment

Most clinician and dental technicians take photographs with hand-held cameras for convenience and expediency. However, there are instances when tripods are invaluable for stabilizing the camera and allowing hands-free operation for precisely positioning flashes and ancillary equipment. In addition, a focusing rail attached underneath the camera is indispensable for fine manual focusing at pre-determined magnifications. The cost of a tripod with a dolly, tripod head and macro focusing stage is around US$ 250. Some relatively inexpensive items are also useful for completing the photographic equipment arsenal including rechargeable batteries, a multi-card reader for transferring images to a computer and imaging or processing software. Table 21.2 itemizes the essential photographic equipment necessary for dental photography, and on a budget, the cost of purchasing all the requisite items is US$ 2705, but if finances are unlimited, the sky is the limit.

Table 21.2 Budget photographic equipment for dental photography[a]

Item	Cost (US$)
dSLR camera body	500
Marco lens—100 mm (or equivalent)	600
Compact ring flash	100
Compact lateral (bi-directional) flashes (2)	500
Bracket for lateral flashes	50
Flash accessories (diffusers, reflectors)	50
Studio flash kit for portraits	300
Backdrops and reflectors for portraits	100
Tripod, tripod head, focusing stage	250
Remote shutter release	100
SD, SDHC, SDXC, CF 16 Gb storage cards (2)	30
Data storage card reader	15
Rechargeable batteries with charger for compact flashes	20
Polarizing filter (circular)	50
UV bulbs	40
Total	US$ 2705

[a] Prices quoted from B&H Photo, Video, Pro Audio (https://www.bhphotovideo.com/c/browse/Digital-Cameras/ci/9811/N/4288586282/1)

21.2.5 Ancillary Items

Besides photographic equipment, there are additional items required for taking intra-oral pictures. The majority of these requisite items are readily available as part of the dental armamentarium, but a few need to be acquired. In order to have access to the cavity, it is necessary to retract the surround-

Fig. 21.5 Selection of cheek retractors of various configurations and sizes

Fig. 21.6 Dental photographic mirrors are available in various shapes sizes to cater for photographing various fields of view

ing lips and cheeks. The most frequent method for retraction is cheek retractors, which come in a variety of ingenious designs, sizes, colours and materials (Fig. 21.5). To this must be added intraoral mirrors, which are used for taking pictures of the occlusal/incisal and buccal/lingual/palatal surfaces of teeth (Fig. 21.6), and contrasters that exclude unwanted anatomy such nostrils when taking maxillary arch views.

A clear field of view is prerequisite for obtain diagnostically useful images. The method used for achieving a clean and dry field depends on the clinical situation and the type of treatment being performed. The choices are rubber dam, gingival retractor cords, cotton wool rolls, gauze or aspiration using a slow-speed saliva ejector or high-speed suction. Also maintaining a dry environment consideration should be given to meticulous cross-cross-infection control and health and safety issues.

21.3 Guidelines and Settings

After gathering the necessary photographic equipment, the next stage is configuring it by ensuring that the settings are optimized for dental applications.

21.3.1 White Balance

The white balance (WB) is simply ‘telling the camera’ about the quality or colour temperature of light. The term ‘white balance’ is used because any ‘white’ part in a scene should be faithfully reproduced as ‘white’ in the image. It is a setting that constantly changes depending on the prevailing illumination. There are three methods for setting the WB: automatically, by manually inputting a numerical value of 5550 K [Kelvin] representing photographic daylight or by using an 18% neutral density grey card. The ideal method for ensuring consistency is using a grey card that is placed in a reference picture before taking the remaining photographs. This reference image is used in imaging software for calibrating all images for a given session to ensure colour fidelity, which is quintessential for medical and dental imagery to prevent misdiagnosis of pathological lesions (Fig. 21.7).

21.3.2 Lighting

Lighting is probably the most important factor for any type of photography. The method by which a light source illuminates an object or subject is by distribution, which is determined by its colour temperature, direction and apparent size [5]. The colour temperature influences colour rendering, and the direction determines the location of shadows and highlights, while the physical size dictates the intensity of the shadows and highlights. For any photographic set-up, the protagonist light is termed the main or key light, which is the primary source of illumination, while secondary light(s) are termed fill lights because they are placed on the contralateral side to literally ‘fill in shadows’ created by the key light. The fill light can be either another flash or a reflector that bounces light from the key light back onto the subject (Figs. 21.8 and 21.9).

Fig. 21.7 White balance: An image showing different colour rendering by altering the white balance setting on the camera (*AWB* automatic white balance)

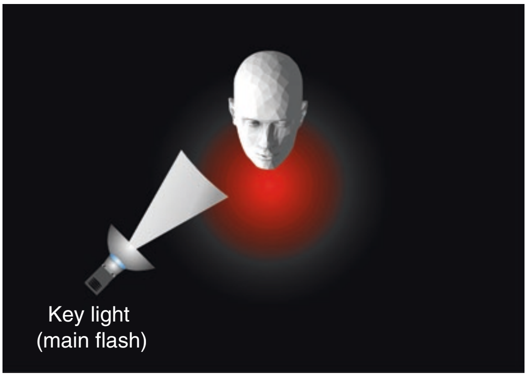


Fig. 21.8 A key light is the primary source of illumination

There is an ongoing debate in dentistry as to which type of lighting is best suited for intra-oral dental photographs: uniform (with ring flash) or unidirectional illumination (with bi-lateral flashes). The ultimate aim of flash photography is producing images where it is difficult to detect whether or not a flash was used. Due to inappropriate illumination, the major flaw with intra-oral dental photography is that it is often blatantly obvious that flashes were utilized to take the photograph. The resultant images appear flat, unnatural and totally devoid of character. In reality, teeth are illuminated by subtle ambient lighting that conveys depth, character and nuances of the dentition, rather than being 'washed out' by harsh illumination. Hence, it is necessary to decide which type of flashes is the ideal choice for a particular type of intra-oral image.

The choices available for extra-oral (dento-facial), intra-oral and bench images are compact bi-lateral or ring flashes. The option of a twin bi-lateral configuration with the flashes positioned 45° to the subject using a balanced flash ratio of 1:1 produces uniformly exposed images with few shadows or highlights. In effect, this set-up behaves similar to a ring flash that produces uniform and shadowless illumination. The resultant

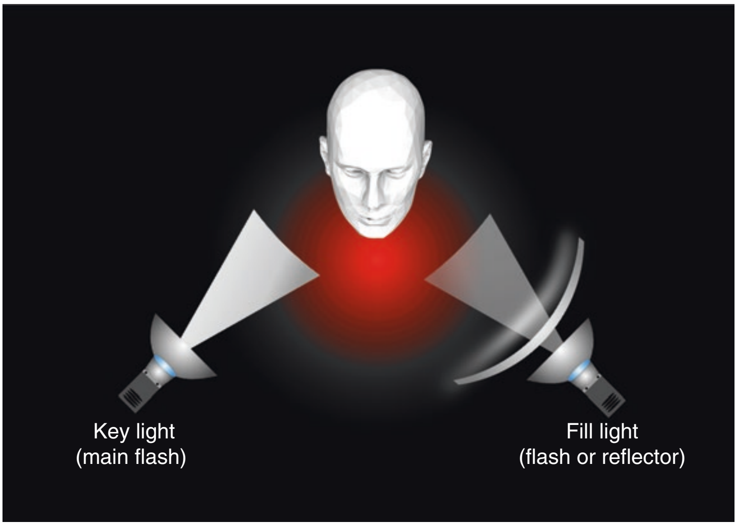


Fig. 21.9 A fill light is the secondary light source that fills in shadows created by the key light

Fig. 21.10 Symmetrical uniform lighting (ring flash) produces lacklustre, bland, two-dimensional imagery

Fig. 21.11 Asymmetrical unidirectional illumination (bi-lateral flashes) produces highlights and shadows that convey a three-dimensional quality rich in detail and depth. Notice that the margins of the defective filling are more easily discernible (compared with Fig. 21.10)

images are lifeless and appear as if they were taken with a flash. To mitigate this effect, asymmetrical unidirectional lighting using a fill flash to key flash ratio of 1:2 is recommended. This means that the key flash (e.g. the right flash) is set to maximum power (full duration or 1/1), while the fill flash output (e.g. the left flash) is muted to half its power (half duration or 1/2).

Alternately, a single flash can be used, with a silver reflector on the opposite side to bounce light back to fill in the shadows. This set-up produces a flash ratio of 1:2 that creates highlights, without completely obliterating shadows on the opposite side, resulting in an image that appears three-dimensional and realistic (Figs. 21.10 and 21.11).

21.3.3 Depth of Field (DoF)

The depth of field (DoF) is the range, or linear distance, in front and behind the point of focus (PoF) that appears sharp. The DoF is not abrupt, but a gradual blurring of the foreground and background of the object that is in focus. This depends on a multitude of factors including the type of sensor, focal length of the lens, distance from the object, aperture, circle of confusion, diffraction, pupil magnification and hyperfocal distance. The hyperfocal distance is the area or point in a scene where focusing will result in the greatest depth of field. The DoF is related to the degree of magnification; the higher the magnification, the sallower the depth of field. The significance of DoF for dental photography is that a macro lens is extremely close to the subject, and therefore the area of sharpness is vastly diminished, limited to only a few millimetres (shallow depth of field). Since the hardware specifications (camera, lens) and visual acuity are unchangeable, the user settings that affect DoF are the aperture and distance of the object (focus distance) from the lens. However, the distance is also unchangeable because achieving a particular magnification, e.g. 1:1, requires a specific distance or minimum focusing distance of a macro lens. Hence, the only parameter to manipulate is the *f* number, which varies inversely with the aperture opening. A large aperture opening (small *f* numbers) results in a shallow DoF, while a small aperture opening (large *f* numbers) results in a deep DoF. Therefore, it is essential to use small apertures (large *f* numbers), e.g. *f* 22, for ensuring focus of all areas of the image. In the case of the intra-oral cavity, it should include focusing as many teeth as possible and large areas of soft tissue. These structures are in different planes and they all need to be in focus. Finally, DoF varies according to the focal length of the lens. Wide-angle lens have greater DoF, but as the focal length increases, the DoF decreases. As well as altering the DoF, the focal length of the lens also changes the distribution of the DoF. For example, the DoF for a standard lens is located equally in front and behind the point of focus. However, with a macro lens, the DoF is distributed approximately 1/3 in front and 2/3 behind the point of focus [6] (Fig. 21.12).

21.3.4 Other Settings

Contemporary cameras offer a huge number of additional settings, many beyond the scope of this chapter. However, the best practice is initially keeping everything to factory default settings. After gaining confidence and experience, and guided by referencing advanced photographic literature, one can fine-tune these settings for stepping up to the next level. Table 21.3 summarizes some commonly used options for dental photography and their corresponding values. These settings need only be carried out once for a specific set-up, and most cameras allow user settings to be stored as ‘user presets’ and recalled when required. For dental photography, two user defined settings are required, corresponding to two basic set-ups: the first for intra-oral, extra-oral and bench shots and the second for portraiture.

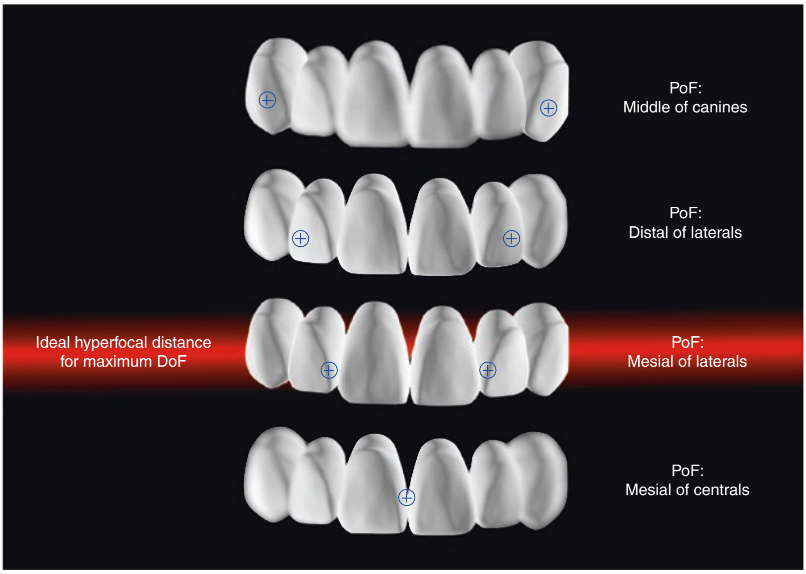


Fig. 21.12 The ideal hyperlocal distance for photographing the maxillary anterior sextant is the mesial aspect of the lateral incisors, which ensures maximum DoF (*PoF* point of focus, represented by the blue cross-line reticles)

Table 21.3 Synopsis of camera settings for close-up and portraiture dental photography

Setting	Close-up or macro (intra-oral, extra-oral and bench shots)	Portraiture
Shutter speed	Compact flash synchronization speed, either 1/125 s or 1/250 s	Any, depending on camera brand and lens, usually 1/125 s
Aperture	*f* 22 N.B. When using intra-oral mirrors, reduce by one *f*-stop to *f* 16 When using contrasters, increase by one *f*-stop, or reduce flash intensity	For standardized clinical portraits *f* 11 is recommended to ensure sufficient depth of field. For non-clinical portraits, any *f*-stop is suitable depending on the desired effect; a good starting point is *f* 5.6
ISO	50–200	50–200
White balance	Manually set to 5500 K, or take reference picture with 18% neutral density grey card	Depending on type of light, for studio flashes manually set to 5500 K, or take reference shot with 18% neutral density grey card
Aspect ratio	Camera default aspect ratio	Camera default aspect ratio
Colour space	Adobe® RGB or sRGB	Adobe® RGB or sRGB
Moirée reduction	Default setting	Default setting
Focusing	Manual focus	Manual or auto-focus
Exposure modes	Aperture priority or manual	Manual
Exposure metering	Compact flashes (TTL or manual)	Manual
Auto-exposure metering mode	Multi-field or multi-zone	Any
Exposure bracketing	None	None
Shutter drive modes	Single	Single
Image data format (file format)	Proprietary RAW, Adobe® DNG (digital negative graphic)	Proprietary RAW, Adobe® DNG (digital negative graphic)
Date/time format	Depending on country	Depending on country
All other settings	Default setting	Default setting
Storage/data transfer	UHS I (30 MB/s writing speed) SD card or UHS II (100 MB/s writing speed) SD card or internal RAM storage	UHS I (30 MB/s writing speed) SD card or UHS II (100 MB/s writing speed) SD card or internal RAM storage
Location (GPS—Global Positioning System)	Personal preference	Personal preference

21.3.5 Location

The location where dental pictures are taken is a contentious issue. For portraiture, there is little disagreement: an allocated room or indeed a tailor-made studio away from the clinical environment. However, for intra-oral images, there is confusion, and the ideal location is debatable. Some operators prefer a non-clinical setting for placing patients at ease and making the photographic session a relaxing experience [7]. However, this may be counterproductive since there is no access to aspiration, there is compressed air and the patient cannot be reclined in the supine position for certain photographic views. Ultimately, this necessitates moving essential dental equipment to a non-clinical setting with the associated compromises in cross-infection and health and safety. There is no doubt that dental photography is a unique genre, and as discussed above, adhering to certain requirements is paramount. Therefore, it is the author's opinion that a clinical setting is best suited for intra-oral photography, fulfilling both clinical requirements and having access to essential dental armamentarium. This is particularly pertinent when photographing surgical procedures, when draping and other asepsis protocols are mandatory for avoiding contamination and when ensuring treatment success.

21.3.6 Delegation

It is tempting to delegate photographic documentation to ancillary staff or assistants [8] or indeed a professional photographer [9]. Delegating has its advantages; it frees up valuable time during a busy daily schedule to concentrate on other pertinent clinical matters. In addition, the clinician may lack competence or be indifferent to taking pictures. However, assigning this responsibility to assistants can prove fruitless. This is not denigrating an assistance, without whom any dental procedure is arduous and often impossible. It is simply allocating tasks that an individual is best trained for, and proficient in, for the followings reasons. First, the assignee should have adequate training in dental photography and be versed with taking both extra- and intra-oral pictures. Second, trying to explain to assistants what an image should depict is asking for a miracle. After carrying out an examination of the patient, it is the clinician who possesses the depth of knowledge and experience for assessing the dental status, including the visual appearance of dental and oral pathology. Only he or she can decide on the type of image that is required and, more importantly, what it should convey [10]. This is similar to taking radiographs, which can only be requested by the clinical after an intra-oral examination. Asking an assistant to take on the role of the clinician is perhaps presumptuous and also expecting too much. Therefore, before appointing a proxy, it is worthwhile asking a few questions: can the delegate differentiate between diseased and healthy tissues, assess defective restorations, perform shade analysis and capture nuances and characterizations of teeth and restorations? Furthermore, is the ensuing frustration of unusable images and extra time needed to repeat them worth the hassle?

21.3.7 Patient Consent

There are varying opinions and ambiguity regarding guidelines about the type of consent necessary for using dental images in both the clinical and non-clinical context [11]. Some believe that no consent is necessary when the images are utilized for therapeutic purposes or for communicating with fellow professional colleagues for the benefit of the patient. This may be justified for emergency treatment or if the patient is incapacitated by a prevailing medical condition and, therefore, unable to grant consent. However, if non-clinical images are used for marketing and promotional endeavours, consent is unquestionably mandatory. Another contentious issue is responding to requests for images from criminal investigators or for forensic identification. In these circumstances, it is best to seek advice from dental professional bodies before releasing images to third parties [12]. As well as gaining appropriate consent, it is essential that confidentiality is safeguarded and dissemination is according to stringent security such as using encrypted e-mails and adhering to HIPAA (Health Insurance Portability and Accountability Act of 1996) guidelines [13].

21.4 Standardization

Dental photography is basically visual dental documentation; its value lies in comparison for self and peer critique of the same or different patients and historical cohort studies for monitoring and research [14–16]. In order to realize these objectives, some form of standardization is prerequisite by establishing guidelines for consistency, comparison and communication [17, 18]. Furthermore, standardization starts at the capture stage when an image is composed and ends at the processing/display stage when the image is edited using a computer software and reproduced with the chosen media (monitor, projector, print), respectively. There are three components that influence standardization: human factors, technical factors and the intended use of the image.

The human factors are the patient; the operator, usually the clinician, who is taking the photographs; and the assistant who ensures patient comfort and helps with positioning dental armamentarium and photographic equipment. The operator factors include sufficient knowledge, training and experience in dental photography and the ability to adapt to patients' idiosyncrasies to avoid jeopardizing the photographic session. The patient factors include the physical and mental state of the patient and whether they are able to fully cooperate with and endure the photographic procedures. This could mean controlling excessive salivary flow or taming involuntary gauging reflexes. In addition, attention needs to be paid to any local soft and hard tissue anatomical variations that may hinder positioning in the horizontal, vertical and sagittal planes. Another issue is obtaining an unimpeded retraction of the extra-oral soft tissues for a clear field of view of the oral cavity.

The quintessential *technical requirement* of an image is that it is sharp, in-focus and correctly composed of the proper colour balance and exposure and records, with fidelity, the object(s) or subject(s) being photographed. This involves understanding basic photographic concepts outlined above and configuring the camera and ancillary equipment settings to produce repeatable and predictable results. The technical aspects include several variables such as dental armamentarium, the camera sensor size, the focal length of the lens, equipment settings, illumination (quality and quantity), lens axis or angle of view (vertical and horizontal composition), background and scaling or magnification.

The last factor to consider is the purpose or *intended use of an image*. The intended use may be clinical documentation, marketing or educational (lecturing/publishing). Clinical documentation also depends on the particular specialty, e.g. orthodontics, periodontics, surgery, oral medicine and aesthetics, to name a few. A portfolio of stock views is adequate for basic documentation, but additional images are required depending on the specialty or a specific treatment modality. For example, a standard set of extra- and intra-oral images are sufficient for cranio-maxillo-facial surgery [19], but inadequate for a ceramist who is fabricating a single unit crown to match an adjacent natural tooth. Another category is marketing and promotion, where image requirements differ from clinical reality. Marketing images serve an entirely different purpose to clinical documentation. They are intrinsically enticing, promoting a given treatment and omitting clinical procedures that may be unpalatable for laypersons, e.g. graphical depiction of surgical procedures. Lastly, recording treatment sequences and outcomes for lecturing and/or publishing are aimed at educating and inspiring a target audience. Hence, these images are different to insipid clinical documentation and incorporate aspirational aspects for enhancing and encouraging the teaching and learning process.

Finally, it is worth mentioning honesty [20]. Current photo-editing software allows even a novice with little or no computer knowledge to transform the 'girl next door' into a 'Mona Lisa'. While this frivolity is harmless narcissism, manipulating clinical documentation is potentially bordering on criminality. This could involve concealing pre-preoperative pathology or enhancing postoperative treatment results by camouflaging defects [21]. In addition, altering images for publishing or lecturing for personal advancement is obviously deceitful. To reiterate, photographs are essentially visual dental documentation, no different to dental records or radiographs. Therefore, strict adherence to medical ethics is paramount, and as professionals, we ultimately rely on fellow colleagues to follow a code of conduct befitting our vocation.

21.5 The Essential Dental Portfolio (EDP)

Depending on the discipline in question, different dental organizations and clinicians advocate varying number of images for a dental portfolio [15, 22–27]. In addition, extra images are required according to individual patient needs, clinical findings and the proposed treatment. The essential dental portfolio (EDP) caters for most dental applications, irrespective of the discipline. Since the intended use of an EDP is clinical photodocumentation, standardization is mandatory, and the guidelines below are intended to ensure that intra- and inter-patient comparisons are possible. This portfolio serves as a record, even if no treat-

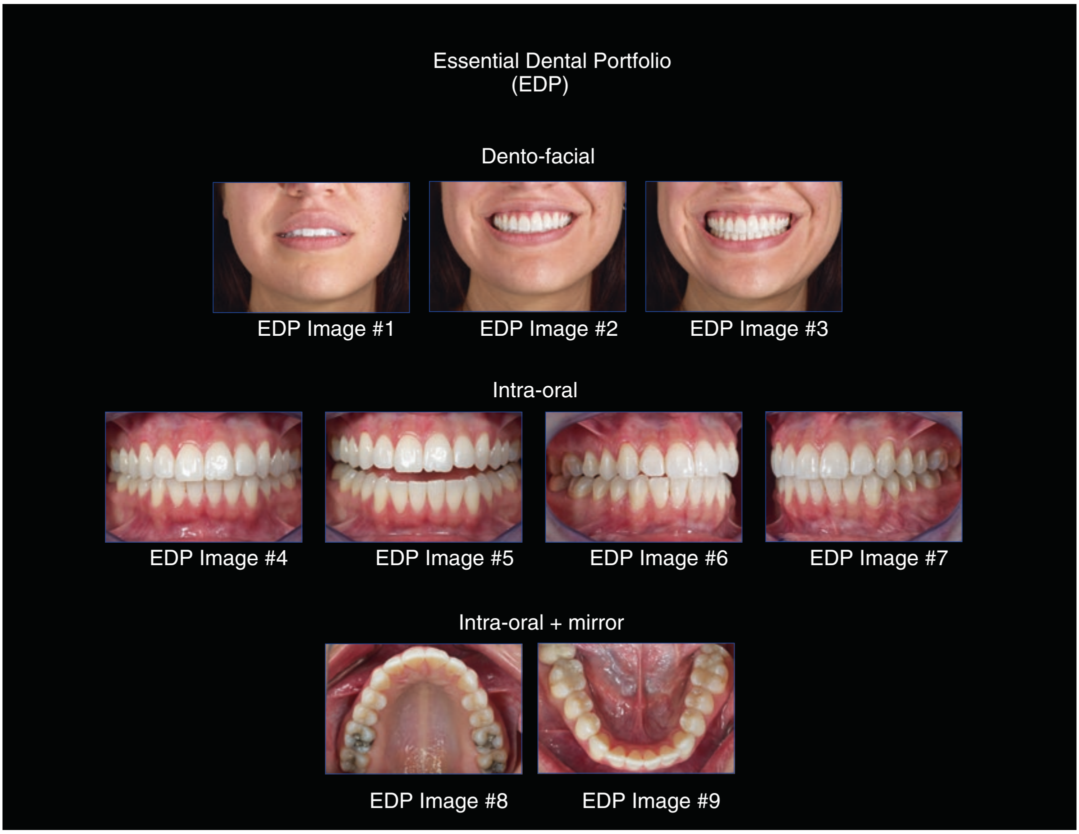


Fig. 21.13 Thumbnails of the essential dental portfolio (EDP)

ment is contemplated, and is an invaluable reference if the patient suffers acute trauma, especially involving the anterior teeth, as a guide for restitution of the traumatized dentition. Furthermore, an EDP is vital for forensic identification, should the patient befall a fatal tragedy.

The EDP consists of nine basic dental views (Fig. 21.13), three extra-oral (dento-facial) and six intra-oral compositions, as follows:

- EDP Image # 1: Extra-oral, frontal habitual or 'rest' lip position
- EDP Image # 2: Extra-oral, frontal relaxed smile
- EDP Image # 3: Extra-oral, frontal laughter
- EDP Image # 4: Intra-oral, frontal view in maximum intercuspation (MI)
- EDP Image # 5: Intra-oral, frontal view with separated teeth
- EDP Image # 6: Intra-oral, right lateral view in MI
- EDP Image # 7: Intra-oral, left lateral view in MI
- EDP Image # 8: Intra-oral, occlusal full-arch maxillary view
- EDP Image # 9: Intra-oral, occlusal full-arch mandibular view

21.5.1 Positioning and Set-Up

The set-up for these images is almost identical, with similar equipment settings, but the intra-oral views require check retractors and intra-oral mirrors. The patient is seated upright in the dental chair and asked to turnaround 90° towards the camera. The cameras can either be tripod mounted with bi-lateral flashes, which is

Fig. 21.14 EDP Images # 1, 2 and 3 set-up: The patient is seated upright facing the camera; the camera is tripod mounted with bi-lateral flashes. The assistant is out of frame, but standing to the side ready to assist and ensure patient comfort (sagittal view)

Fig. 21.15 EDP Images # 1, 2 and 3 set-up: Photographer's PoV

ideal for EPD Images # 1, 2 and 3. The positioning of the photographer and patient is shown in Fig. 21.14 (sagittal view) and photographer's PoV (point of view) in Fig. 21.15. For the intra-oral views, the assistant is at hand with a saliva ejector and 3-in-1 syringe to maintain a dry field of view (Figs. 21.16 and 21.17). It is advisable to take the extra-oral pictures first before moving onto the intra-oral images to avoid transient creasing or redness of the lips caused by the cheek retractors, which may be apparent in the photographs. The occlusal views of each arch are accomplished by capturing the reflected images in the intra-oral mirrors. A contraster is particularly useful for hiding extraneous anatomy such as nostrils when photographing the maxillary arch (Fig. 21.18).

Fig. 21.16 EDP Images # 4, 5, 6 and 7 set-up: The patient is seated upright facing the camera and holding the bi-lateral plastic cheek retractors; the camera is hand-held with a ring flash. The assistant holds the saliva ejector and 3-in-1 dental syringe (sagittal view)

Fig. 21.17 EDP Images # 4, 5, 6 and 7 set-up: The patient is seated upright facing the camera and holding the bi-lateral plastic cheek retractors; the camera hand-held with a ring flash. The assistant holds the saliva ejector and 3-in-1 dental syringe (bird's-eye view)

Fig. 21.18 EDP Image # 8 set-up: The patient's head is titled downwards. The patient holds the intra-oral occlusal mirror, while the assistant holds the contraster and 3-in-1 dental syringe to blow air onto the mirror. The photographer aims the lens axis 45° at the mirror (photographer's PoV)

21.5.2 Settings and Field of View

The photographic equipment settings are very similar for all EDP, with minor modifications for the magnification factor and aperture. Table 21.4 summarizes the guidelines and configuration of the camera and flashes.

The field of view varies according to the type of image. For extra-oral EDP Images # 1, 2 and 3, the images are framed to include the tip of the nose and the menton of the chin, which allows assessment of the dental midline in relation to the facial midline. The point of focus (PoV) is the philtrum of the upper lip or canines during a relaxed smile or laughter (Figs. 21.19 and 21.20). The PoF for EDP Images # 4 and 5 is the maxillary canine tips to ensure maximum DoF (depth of field), but varies depending on the shape of the arches. If all teeth are not in focus, the point of focus may need to be altered either anterior or posterior to the canines (Figs. 21.21 and 21.22). For the lateral views of the arches (EDP Images # 6 and 7), the PoV is the cusp tips of the maxillary first premolar, and lastly, the PoV EDP Images # 8 and 9 is the occlusal surfaces of the maxillary or mandibular second premolars (Figs. 21.23 and 21.24). Also, the reflected EDP Images # 8 and 9 need to be laterally inverted (flipped) and rotated in imaging software for ensuring the correct perspective.

Table 21.4 Settings and guidelines for EDP images

Item	Setting/description	Notes
Focus	Manual	
Exposure metering	TTL or manual	Manual: take a few test shots to ascertain correct exposure, or use histogram
ISO	50–200	
Aperture	*f* 22	*f* 16 when using intra-oral mirrors
Shutter speed	1/125 s or 1/250 s	Flash synchronization speed depends on a specific camera brand
Image data format (file format)	RAW or DNG	
White balance	AWB (automatic white balance), 5500 K or manual	Manual: numerical value input, or take a reference image with an 18% neutral density grey card
Flash	Twin bi-lateral flashes with diffusers angled 45° or ring flash	Adjust fill light: key light ratio to 1:2. If images are too bright or too dark, adjust intensity of flashes, or move flashes closer or further away until correct exposure is achieved (only applicable for bi-lateral flashes as ring flashes are usually fixed on the front of the lens)
Magnification factor	1:5 (extra-oral) 1:2 (intra-oral)	Only relevant for full-frame sensors, or set predefined focusing distance on lens, or use anatomical landmarks (see field of view below)
Point of focus (PoF) represents the ideal hyperfocal distance for maximum DoF (depth of field)	The point of focus depends on the view. For extra-oral views, the PoV is the philtrum of the lips; for intra-oral views, the PoV varies according to the FoV and is centred to obtain maximum DoF (see text)	Hand-held cameras: for predefined magnification or focusing distance, move camera backwards and forwards until focus is obtained, or use anatomical landmarks for composing (see field of view below) Tripod mounted camera: for predefined magnification or focusing distance, use macro stage for focusing, or use anatomical landmarks for composing (see field of view below)
Field of view (FoV)	Extra-oral: tip of nose to menton Intra-oral: variable	(See text)
Background	Neutral background or anatomical landmarks (see text)	Standardized clinical images: Neutral, e.g. sky blue or grey

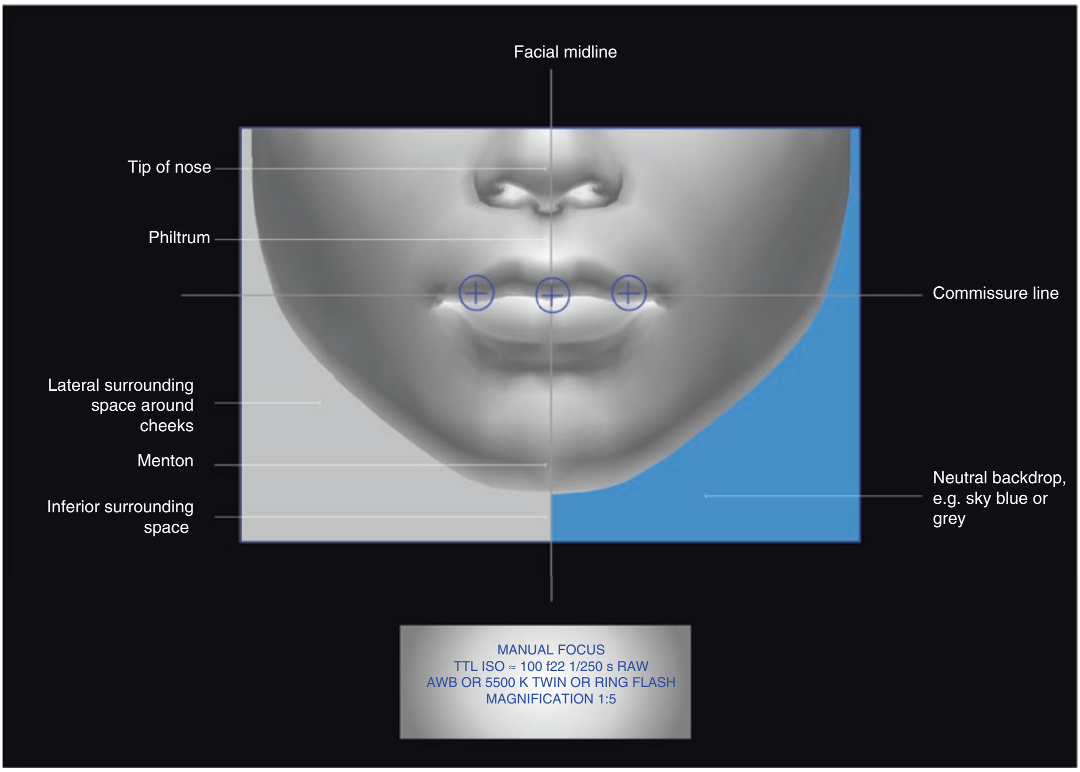


Fig. 21.19 Photographic settings and field of view for dento-facial compositions, EDP Images # 1, 2 and 3 (PoF [point of focus] = blue cross-line reticle. NB. For a relaxed smile, the PoF is the central incisors 9 or philtrum, and for laughter, the PoF are the canine tips)

Fig. 21.20 EDP Image # 1

21.6 Optional Images

Depending on the specialty, in addition to the EDP, several optional extra- and intra-oral images may be required. These can be either deferred to a later date or preferably taken at the same session to avail the photographic set-up of the EDP. The optional image may include right and left extra-oral profile (Fig. 21.25) and oblique and submental oblique views for assessing lip competence, maxillary incisal edge position and inclination in relation to the

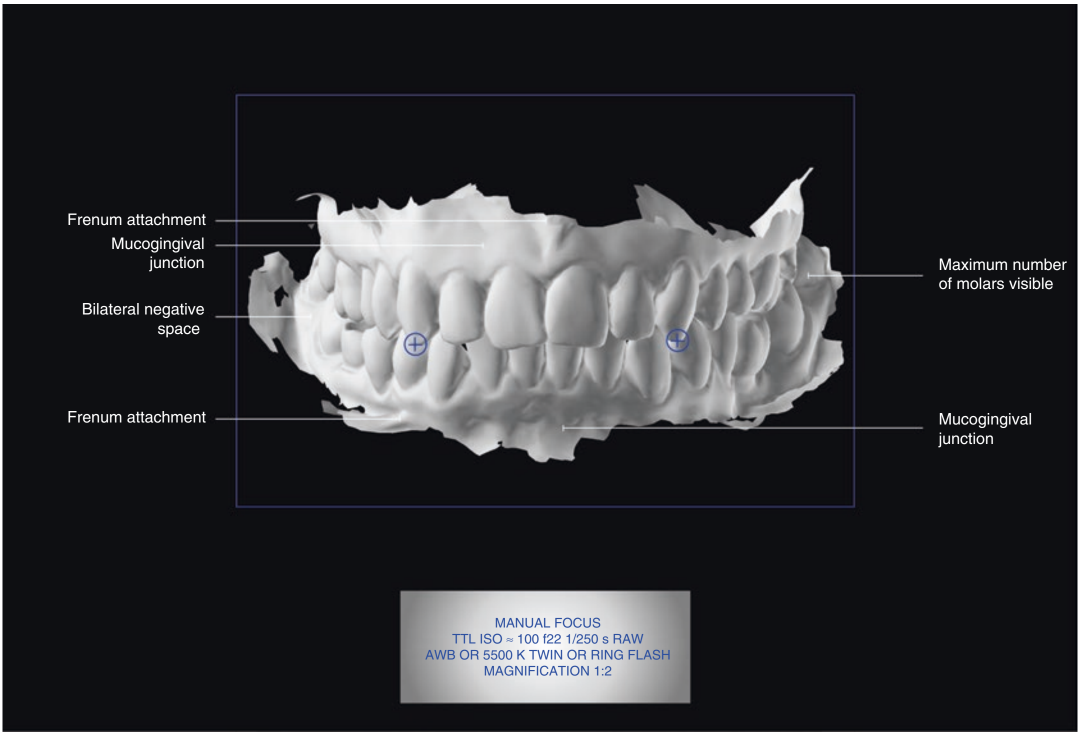


Fig. 21.21 Photographic settings and field of view for intra-oral compositions, EDP Images # 4 and 5 (PoF = blue cross-line reticle)

Fig. 21.22 EDP Image # 5 with teeth separated

mandibular lip, aesthetic analysis such as smile line or excessive gingival display (gummy smile). The optional intra-oral views include lateral views of the teeth separated; submental oblique views for overjet/overbite measurements; sextant and quadrant compositions from various perspectives such as occlusal, buccal and palatal/lingual; or extreme magnification, with or without a polarizing filter, for shade analysis and tooth characterization as a guide for replicating these nuances in artificial restorations.

Another use of optional images is to document a series of photographs for teaching a particular clinical technique. The prerequisite for these images is consistency by ensuring an identical field of view (framing), cropping and magnification. For example, the following series of images show aesthetic crown lengthening for correcting excessive maxillary gingival display due to altered passive eruption (APE) [28] and rehabilitating pink and white aesthetics [29] of the maxillary anterior sextant to acceptable norms (Figs. 21.26, 21.27, 21.28, 21.29, 21.30 and 21.31).

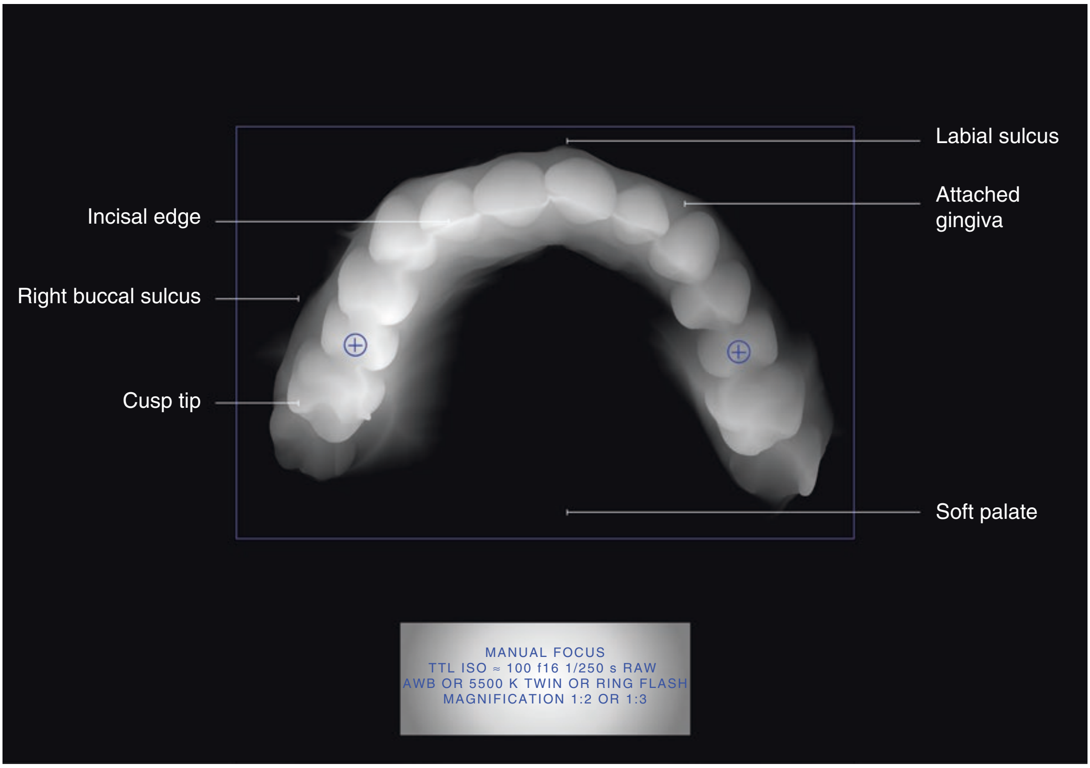


Fig. 21.23 Photographic settings and field of view for EDP Image # 8 (PoF = blue cross-line reticle)

Fig. 21.24 EDP Image # 8

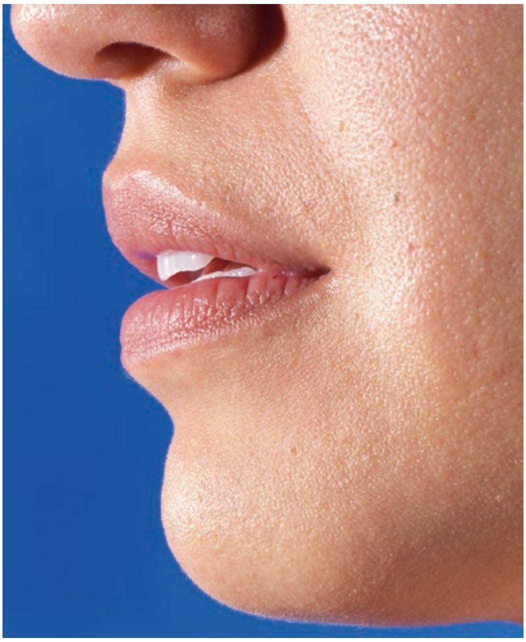


Fig. 21.25 Optional left profile extra-oral view

Finally, it is worth remembering that to obtain textbook standard images requires an ideal patient, ideal nurse, ideal photographer, ideal equipment, ideal temperament and ideal environment. However, in reality, these utopian conditions are elusive. Therefore, a compromise is inevitable. This may include accepting less than ideal fields of view, visible edges of check retrac-

Fig. 21.26 Preoperative clinical status showing short clinical crown lengths of the maxillary anterior teeth with excessive gingiva due to APE

Fig. 21.27 Preoperative 3D printed models showing the proposed levels of the maxillary gingival zeniths for surgical aesthetic crown lengthening

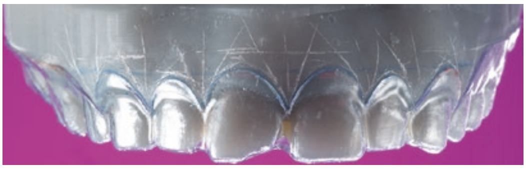


Fig. 21.28 Thermoformed transparent acrylic surgical guide for crown lengthening

tor or mirrors, poor angulations, copious saliva or fogging of mirrors, to name a few fallibilities.

21.7 The Essential Portrait Portfolio (EPP)

While the essential dental portfolio (EDP) concentrates primarily on the teeth, the essential portrait portfolio (EPP) consists of basic full face images and the relationship of the teeth to the face. The EPP is quintessential for a variety of dental disciplines including orthodontics, prosthodontics, periodontics, restorative dentistry, implantology, peadodontics, smile analysis, smile design and facial enhancement and cranio-maxillo-facial procedures. The clinical portraits

Fig. 21.29 Surgical guide in situ with periodontal probe measuring the proposed gingival zeniths

Fig. 21.30 Gingivectomy to new gingival zeniths according to surgical guide, followed by ostectomy and osteoplasty to create adequate space for the biological width

Fig. 21.31 Postoperative result after aesthetic crown lengthening and direct resin-based composite fillings to appropriate width/length ratio of the maxillary anterior teeth (compare with Fig. 21.26)

are excluded from the EDP since some patients are reticent to give consent to photograph their face due to personal, social, cultural or religious reasons. However, if this is not a concern, and appropriate consent is obtained, the EPP can be added to the EDP making a complete set of 16 images.

The EPP consists of seven views (Fig. 21.32), as follows:

- EPP Image # 1: Frontal view with inter-labial separation
- EPP Image # 2: Frontal view—relaxed smile
- EPP Image # 3: Frontal view—biting wooden spatula
- EPP Image # 4: Profile right side—inter-labial separation
- EPP Image # 5: Profile left side—inter-labial separation
- EPP Image # 6: Oblique right side—inter-labial separation
- EPP Image # 7: Oblique left side—inter-labial separation

21.7.1 Positioning and Settings

For clinical portraits, the patient is seated upright in a revolving chair, hair tied back to exposure the auricles, ostentatious jewellery removed, and cosmetic make-up muted or washed off to capture natural skin tones and texture. There are several reference lines that are utilized for orientating the head in the vertical and horizontal planes, including the interpupillary and facial midlines, ala-tragus line (Camper's plane) or Frankfort plane (Fig. 21.33). However, it is important not to rely on the incisal or occlusal plane as a reference, as this may be eschewed and result in pseudo-alignment. The photographer is situated behind camera, which can be tripod mounted [ideal for standardization] or hand-held about 1–2 m away from the patient. The camera is adjusted so that the lens axis is at the same level as the middle of the face. The dental assistant is at hand helping set up the photographic equipment while keeping a vigilant eye on the patient for ensuring their comfort.

The photographic equipment settings for standardized clinical portraits are as follows. The magnification factor ranges from 1:8 to 1:15, depending on the size of the patient's physical build and whether the camera has a full-frame sensor. An alternate approach is setting a pre-defined focusing distance on the lens barrel or framing the picture according to the field of view. A *f* 11 aperture is recommended for adequate depth of field with a 1/125 s or 1/250 s shutter speed to eliminate the influence of ambient light. The ideal location for portrait is a dedicated or makeshift studio using studio flashes (Figs. 21.34 and 21.35). The salient camera/flash settings and guidelines are outlined in Table 21.5.

The frontal views, EPP Images # 1, 2 and 3, are taken with the patient looking straight towards the cameras, while for profile and oblique views, the patient is asked to turn on the revolving chair until the desired angle of view is obtained. Similar to the dento-facial, inter-labial separation is achieved by asking the patient to iterate the letter 'm' or 'Emma' for the EDP Image # 1. For EPP Image # 2, a relaxed smile is captured [usually accompanied by narrowing of the inter-eyelid spaces]. The EPP Image # 3 is biting into a wooden spatula with the head positioned to the horizontal. The angulation of the spatula is ideal for assessing the incisal/occlusal plane alignment to the interpupillary line.

21.7.2 Field of View

The field of view, or composition, depends on the aspect ratio setting on the camera or the aspect ratio used in imaging software to crop the images. For portraiture, the chosen aspect ratio determines the amount of background space at the upper, right and left borders of a composition (the lower border is bounded by the sterno-clavicular joint). There are two options: The first is to be consistent with the EDP and use a landscape aspect ratio, which ensures standardization for both the dental and

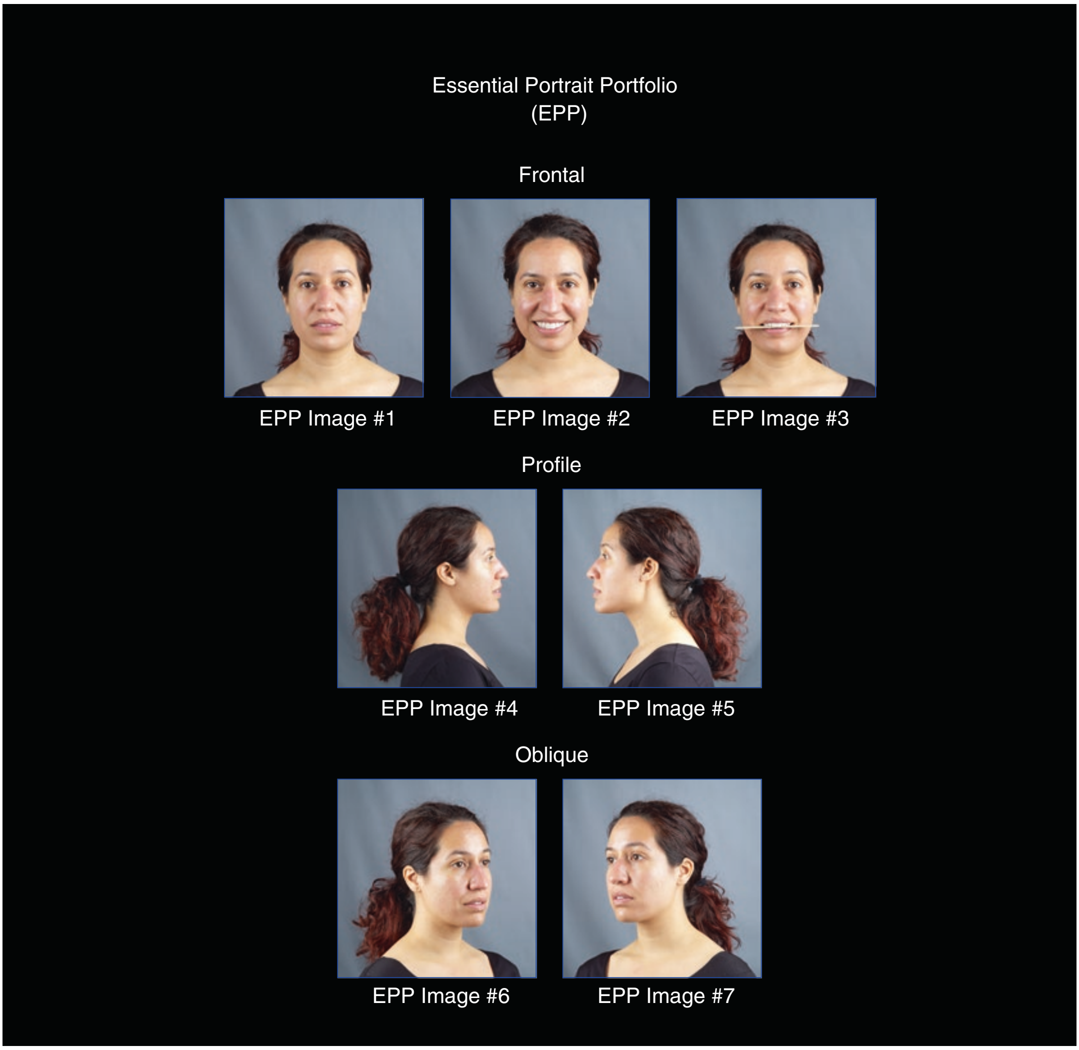


Fig. 21.32 Thumbnails for the essential portrait portfolio (EPP)

clinical portrait portfolios. However, landscape orientation for portraits results in larger empty spaces right and left sides of the face compared to the upper border. The second option is to frame/crop the images with reduced amounts of background on the right and left sides, using the so-called 'portrait' aspect ratio, but the framing is obviously disparate with the EDP.

The point of focus (PoF) also differs according to the angle of view. For frontal views, the PoF is usually the rhinion or bridge of the nose (Fig. 21.36). For profile views, EPP Images # 4 and 5, the contralateral side should be totally invisible, and the PoF is on the ala-tragus line, at the midpoint between the tragus and lateral canthus of the eye. Finally, for oblique views, EPP Images # 6 and 7, the contralateral eye and its upper and lower eyelashes are visible, and the PoF is on the ala-tragus line at the intersection of the lateral canthus.

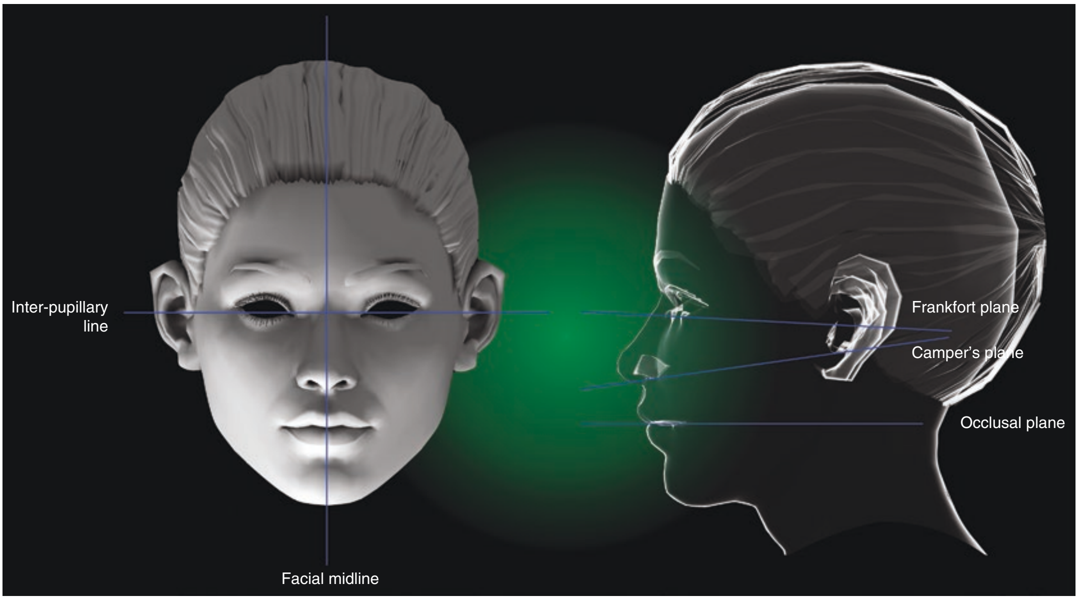


Fig. 21.33 The imaginary facial lines are useful guides for orientating the head in the horizontal and vertical planes. References lines can be seen: on the left side, interpupillary and facial midline; on the right side, Frankfort, Camper and occlusal plane

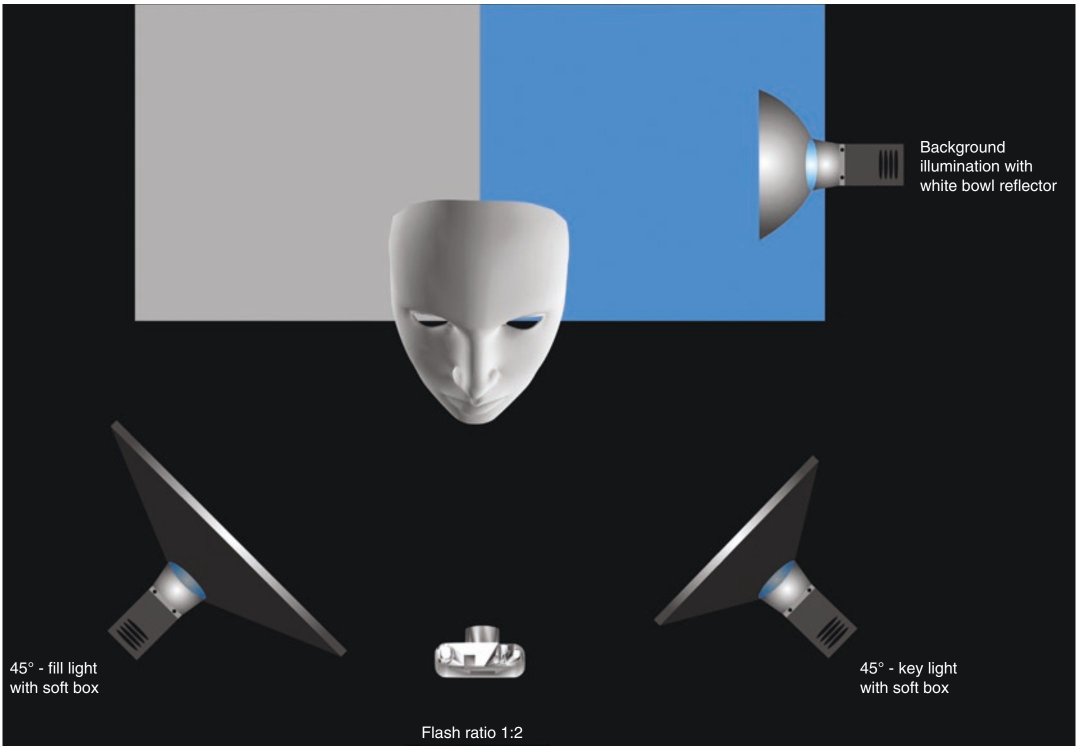


Fig. 21.34 Schematic representation of the set-up for EPP

Fig. 21.35 Set-up for clinical portraits consists of three flashes, a key and fill light to illuminate the subject and a third flash directed towards the background

21.8 Clinical vs. Non-clinical Portraits

As previously mentioned, there are two types of dental portraits, clinical and non-clinical. The former has been outlined above and yields unadulterated information that is essential for analysis and diagnosis. However, non-clinical portraits are also required for marketing and promotion. These are suggestive and alluring images, tainted by the subject's wishes and the photographer's vision. Since clinical portraiture is harsh reality, standardization is essential for comparison, interdisciplinary communication as well as gauging treatment progress and monitoring treatment outcomes. Alternately, non-clinical portraiture enhances attractiveness and is primarily narcissistic. Both types of images serve different purposes; clinical portraits deliver reality, while non-clinical portraits steer into glamour, fantasy and surreal territory (Figs. 21.37 and 21.38). Therefore, for non-clinical portraits, the rule book is discarded, and the photographer has carte blanche and, depending on his or her artistic slant, is free to experiment and 'paint' a unique picture of the patient's persona [30, 31].

21.9 Processing

The second part of the CPD triad is processing the photographs with imaging software after transferring them to a computer. Although image processing is a complex procedure, it can broadly be categorized as editing or manipulation [32]. This is analogous to writing a prose or narrative, where editing text involves corrections that allow the reader to more easily comprehend the message that is being conveyed, but not altering the

Table 21.5 Settings and guidelines for standardized clinical portraits

Item	Setting/description	Notes
Focus	Manual or auto-focus	
Exposure metering	Manual or TTL	Manual: use light meter, histogram or take test shots to ascertain correct exposure
ISO	50–200	
Aperture	*f* 11	
Shutter speed	1/125 s or 1/250 s	Flash synchronization speed depends on a specific camera brand
Image data format (file format)	RAW or DNG	
White balance	Automatic or manual	Manual options: numerical value input (5500 K), or take a reference image with an 18% neutral density grey card
Flash	Two studio flashes with soft boxes or umbrellas, angled 45° towards patient, third flash to illuminate background	Set the two flashes aimed at patient to a fill light: key light ratio of 1:2, alter intensity or distance of flashes to achieve correct exposure
Magnification factor	1:8 to 1:15	Only relevant for full-frame sensors, or set predefined focusing distance on lens, or see below for field of view
Point of focus (PoF)	The point of focus will depend on the angle of view, e.g. rhinion or bridge of the nose for frontal views	Hand-held cameras: for predefined magnification or focusing distance, move camera backwards and forwards until focus is obtained, or use anatomical landmarks for composing (see field of view below) Tripod mounted camera: for predefined magnification factor or focusing distance use macro stage for focusing, or use anatomical landmarks for composing (see field of view below) If using auto-focus, ensure that the lens axis is centred on the tip of the nose for frontal views
Field of view (FoV)	Variable depending on types of view	See text
Background	Variable	Neutral, e.g. sky blue or grey

message. In other words, *manipulation* alters the message or tells a different story to that of the original, while *editing* an image simply corrects technical issues without making alterations to the content of the image, i.e. the song remains the same. Image manipulation disguises or alters the image content and, therefore, its tune to tell a different story. However, the line between editing and manipulation is often blurred, and depending on opinions, some regard even the slightest alterations as forms of manipulation [33].

21.9.1 Imaging Software

There is an abundance of imaging software on the market, and the choice is unique to every photographer depending on cost, features and ease of use. At this juncture, the clinician or dental technician needs to ask him-/herself: is the photographic documentation solely limited for dental use, a quasi-passion or aiming to be creative and/or achieving professional heights? If the answer is solely for dental purposes, then any simple photo-editing software with basic functions will suffice, e.g. Apple® Photos, Microsoft® Photos, Google® Photos, etc. These software are free; have intuitive interfaces; have a vertical learning curve, with many one-click preset options; are easy to use; and serve the majority of dental needs. For the intermediate or enthusiastic level, the choices are GIMP, Movavi Photo Editor, Corel®AfterShot Pro, Pixelmator, Serif Affinity Photo, IrfanView and

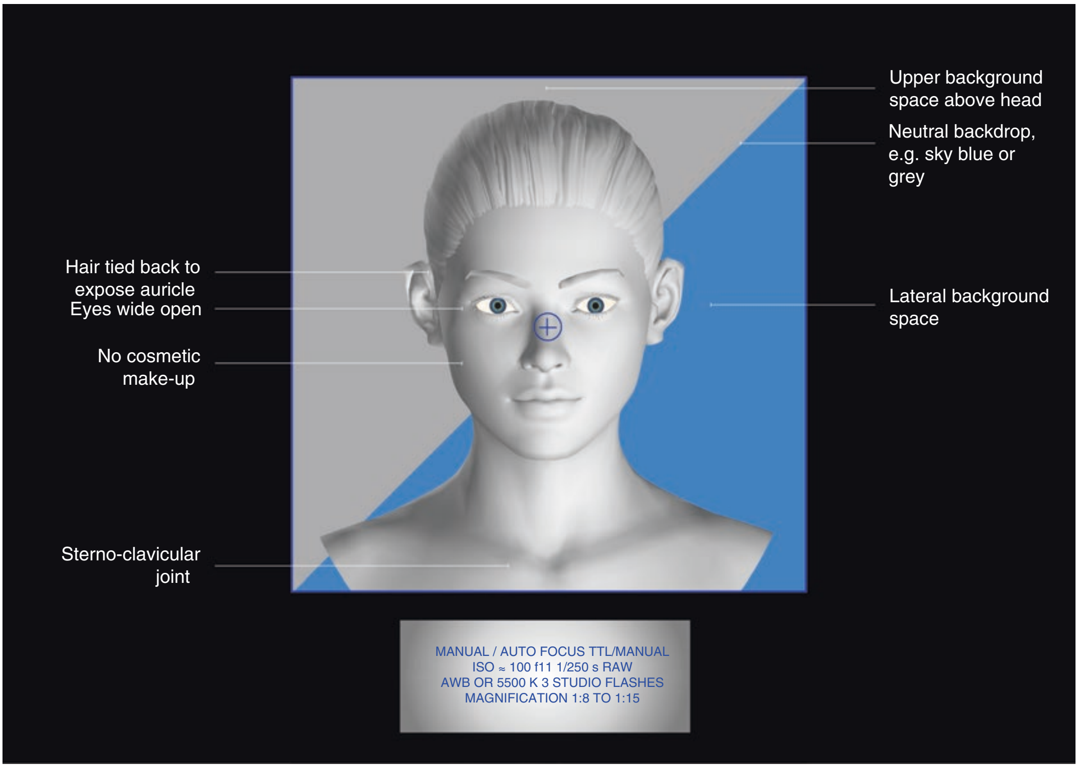


Fig. 21.36 Standardized clinical portraiture settings, field of view and PoF (blue cross-line reticle) for EPP Images # 1, 2 and 3

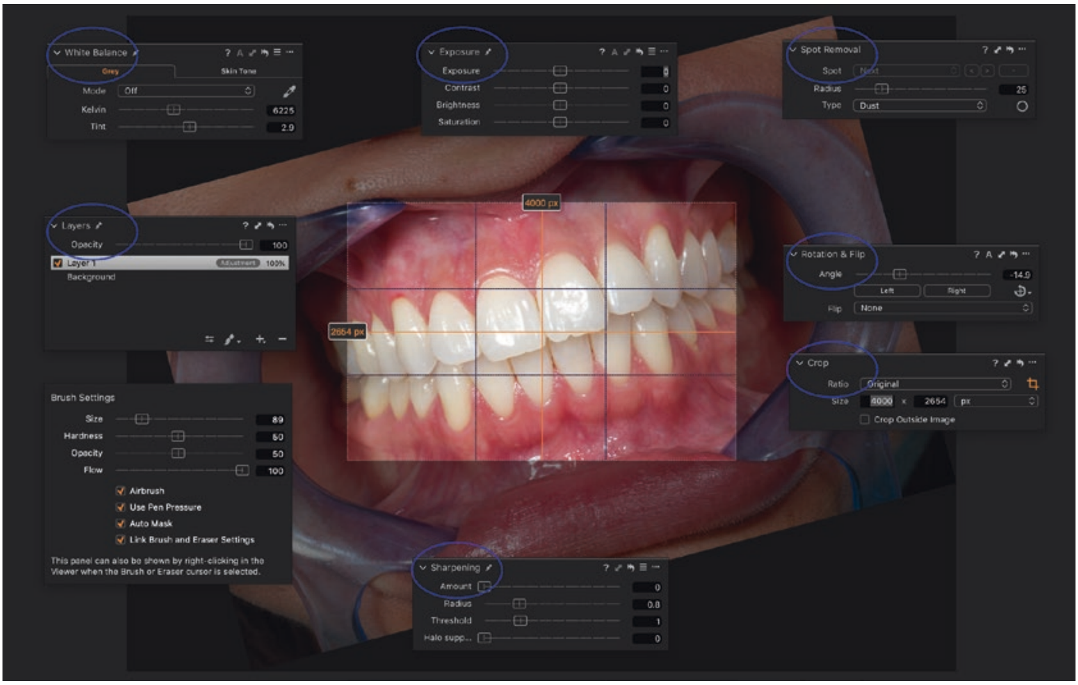
Fig. 21.37 Clinical portrait with high clinical value, but low marketing value

Fig. 21.38 Non-clinical portrait with high marketing value, but low clinical value

Adobe® Photoshop Elements. These programs are more time-intensive to master, but offer many creative and preset features unavailable in basic versions. Lastly, if the intention is to be more creative, spend unlimited time learning new features and jump to a professional level, the software of choice can be Adobe® Creative Cloud, ACDSee or Capture One. Photoshop (part of Adobe® Creative Cloud) is undoubtedly the industry standard, offering both image editing and manipulation and creativity limited only by the imagination; if you cannot do it in Photoshop, it probably cannot be done. ACD Systems offer several software for processing, a powerful drawing and painting program plus a cataloguing image management system. Capture One is essentially an image editing software, with extensive presets, LUTs (lookup tables) and a few manipulation effects plus comprehensive cataloguing facilities. The philosophy behind this software is processing images, without compromise, to their maximum potential, i.e. image quality, and only image quality, is the order of the day. Capture One (current version 12) is made by Phase One®, a company that manufactures high-end digital cameras. The software interface is geared for the professional, with intuitive menus and unique features that bring out the best in any image. Furthermore, the software is backed by helpful technical support, video tutorials, forums and blogs for expediting the learning process.

21.9.2 Editing Images

As dental images are dento-legal records, alterations should be restricted to technical issues that allow the observer to 'read' the image more clearly, not unlike correcting typographical errors in text. In addition, limiting the amount of alterations also preserves image quality, which is essential for maintaining consistency. Hence, for clinical fidelity, image editing is ethically permissible and indeed beneficial. On the other hand, stringent restrictions do not apply to images intended for marketing purposes, and therefore, manipulations for enhancing appeal and attention are acceptable. While there is no substitute for good photographic technique at the capture stage, nearly all images require some form of retouching to polish the final result, no different to polishing a diamond for maximizing its optical properties. These adjustments are part of the post-processing workflow that is performed sequentially starting with colour spaces, white balance, exposure, orientation and cropping, removing artefacts (dust particles), local adjustments (layers) and, lastly, sharpening (Fig. 21.39). Although this is a trun-


White Balance
Grey | Skin Tone
Mode: Off
Kelvin: 6225
Tint: 2.9

Exposure
Exposure: 0
Contrast: 0
Brightness: 0
Saturation: 0

Spot Removal
Spot: Next
Radius: 25
Type: Dust

Layers
Opacity: 100
☑ Layer 1 Adjustment 100%
Background

Brush Settings
Size: 89
Hardness: 50
Opacity: 50
Flow: 100
☑ Airbrush
☑ Use Pen Pressure
☑ Auto Mask
☑ Link Brush and Eraser Settings
This panel can also be shown by right-clicking in the Viewer when the Brush or Eraser cursor is selected.

Rotation & Flip
Angle: -14.9
Left | Right
Flip: None

Crop
Ratio: Original
Size: 4000 x 2654 px
☐ Crop Outside Image

Sharpening
Amount: 0
Radius: 0.8
Threshold: 1
Halo supp...: 0

Fig. 21.39 Processing dental images is restricted to editing involving adjusting colour spaces, white balance, exposure, orientation and cropping, removing artefacts, local adjustments and sharpening cated list of tasks that are not applicable for every image, nevertheless, it represents the salient adjustments that are essential for image editing. In addition, choosing the appropriate file format depends on the intended use. Ideally, all capture should be performed with the propriety RAW format of a specific camera brand and after editing exported to high-quality TIFF (Tagged Image File Format) for archiving, presentations or publishing. The JPEG (Joint Photographic Experts Group) format is ideal for e-mail attachments, web publishing and social media. Finally, it cannot be overstressed that the need to maintain confidentially of medical and dental images is sacrosanct. Therefore, dissemination and storage should be secure and fool-proof to prevent inadvertent disclose or loss of highly sensitive data. The final part of the CPD triad is display, which consists of viewing images on a monitor, a projector or traditional printing methods.

21.10 Additional Dental Images

Although not the remit of this chapter, dental photography also consists of bench images or close-up macrophotography, which is ideally suited for analysis (Fig. 21.40), graphically showing techniques (Fig. 21.41), or simply having artistic flare with high visual impact. The possibilities offered by dental photography are truly endless for the imaginative and creative mind (Figs. 21.42 and 21.43).

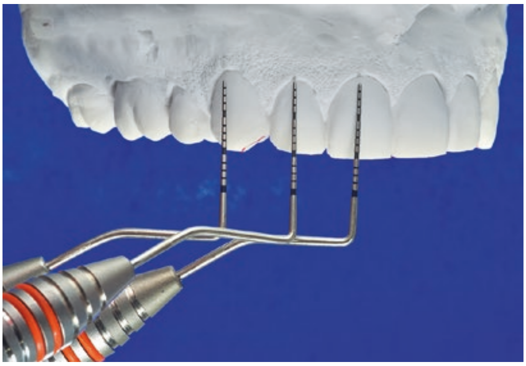


Fig. 21.40 Bench images of plaster casts are ideal for analysing the proportion of teeth

21.11 Future Considerations

This chapter has outlined the basics of capturing standardized dental images. However, considering the resolution of the human eye, which varies from 324 megapixels (90° angle of vision) to 576 megapixels (120° angle of vision), an 18 megapixels average camera sensor lags far behind [34]. Nevertheless, resolution is not everything, and depending on the intended use, a modest megapixel sensor is sufficient for most modalities.

In spite of this, the future of digital photography using conventional cameras is being challenged by the ubiquitous smartphones. The last few decades have witnessed an exponential

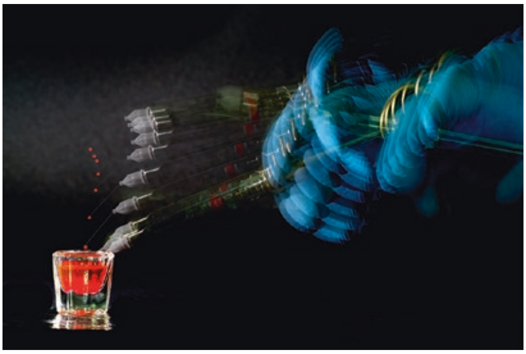


Fig. 21.41 Bench images showing a particular technique

Fig. 21.42 Bench images showing artistic effects for visual impact

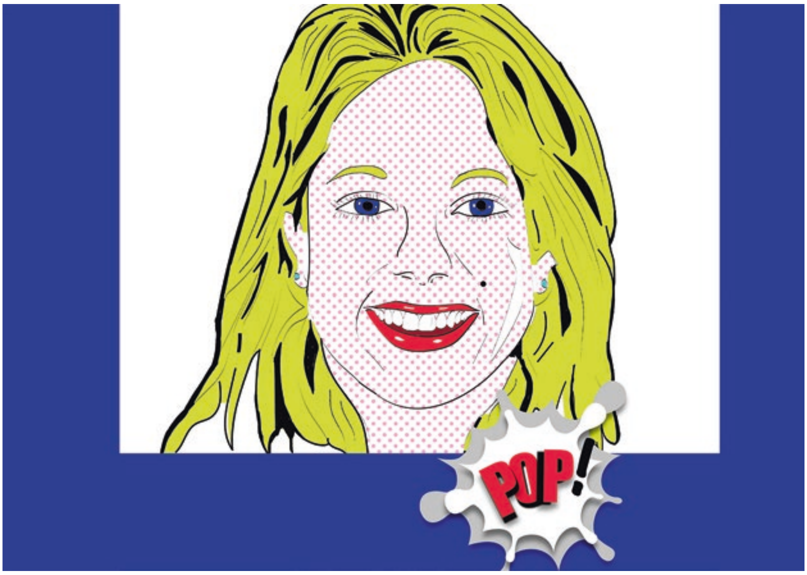


Fig. 21.43 Stylised imagery emulating the style of famous artists such as Roy Lichtenstein

increase in preference for the convenience offered by smartphones, which are capable of delivering quality images that where once only possible with dedicated digital cameras. In addition, many reputable camera manufacturers such as Leica®, Hasselblad® and Carl Zeiss® are collaborating with phone companies to develop cameras and accessories for mobile hardware. The convenience, expedience and connectivity offered by smartphones and tablets are obviously the driving force for this rapidly evolving industry. Also, there is a discussion in the dental literature about the suitability of cellphones or tablets for dental photography [35]. The main purpose of smartphone cameras is that they are designed for social photography. Hence, to use these units for medical/dental purposes, the in-built cameras need to be calibrated and modified for macro use. While dissemination of images offered by mobile devices is unmatched, to achieve clinically useful images requires training. However, smartphones are ideal for random shots showing patients' particular oral problems or sharing cursory images with dental technicians or specialists regarding oral rehabilitation. Nevertheless, this technology is difficult to dismiss, and as these devices evolve, they may be supersede conventional digital cameras for photodocumentation for many fields, including dentistry.

Moving on from two-dimensional (2D) to three-dimensional (3D) imaging, we already have both intra-oral and extra-oral scanners that are capable of reproducing the oral cavity and facial scans, respectively. Taking a leap from 2D to 3D image acquisition obviously offers innumerable advantages for treatment planning, delivery, assessing outcomes and monitoring. 3D captures represent an object in true three-dimensional reality that can be viewed from any perspective or angle without having to take a series of 2D images from different fields of view. The major drawback of 3D acquisition is that while it captures the anatomical form or morphology of an object, it cannot reproduce the nuance of colour, which subsequently needs to be added in software by texture mapping. Taking another leap forwards, 4D imaging is on the horizon, which can capture facial expressions for analysing palsies or involuntary twitches and mood analysis [36].

To summarize, the future of image acquisition is both exciting and unimaginable and is destined to change the practice and delivery of dental and medical care. Furthermore, devices for 3D and 4D captures, which may seem anachronistic in today's practices and clinics, are poised to be part of routine armamentaria in the next decade.

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Laboratory Imaging and Photography

22

Michael Peres

Contents

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22.1 Introduction

This chapter overviews the making of photographs of laboratory subjects. It will not discuss patient photography where close-up techniques are also used. Photographing patients requires different considerations beyond the scope of simply operating a camera equipped with a close-up lens.

22.2 Making Laboratory [Close-Up] Photographs

Close-up pictures play an important role in the preservation of factual data about all kinds of subjects, including petri dishes, small and specialized medical equipment, tissue biopsies, or prepared tissue sections evidenced as microscope slides.

Making photographs in a lab requires the use of some relatively common equipment. This would include an appropriate camera, special lenses, a camera stand or tripod, and artificial light source(s).

Close up photography involves making pictures of objects that would be 1/10th or 1:10 life-size and ranges down include 1:1 or life-size when compared to the subject. *Photomacrography* magnifies images when compared to the object size and creates images with a magnification that begins at approximately life-size and ranges up through approximately 25×. *Stereo microscopes* produce images that also begin at life-size and typically have an upper range of 80–100× depending on the primary objective. *Photomicroscopes* have a low-end magnification of approximately 2–4× and can magnify images approximately 1000×. These definitions are relative since imaging now includes many software solutions that create images that are outside of these ranges.

22.3 Always Use a Scale

It is an expectation that photographs used for scientific or photo-documentation includes a ruler or scale. The ruler scale needs to be placed near to the object and also at the zone of best focus if possible. Scales can be added before or after photographing a sample if the process used to calculate their length is correct. Rulers can be white, black, colored, or shiny. Medical/scientific photographs require the use of the highest-equipment available at the time of the making. This includes the ruler scale.

22.4 Optimizing Camera and Modes of Operation Setting Used for Laboratory Imaging

Often, photographs are made in a hurry and profiling the camera and lens settings is neglected. Making pictures without optimizing the camera, optical elements, and illumination settings will lead to suboptimal digital image files. There are several modes that a camera can and should be operated when producing laboratory photographs. These modes include both manual and automatic. There are also several secondary modes that control features of the camera's operation but will not be discussed here in detail. There are good reasons why each mode should be selected for use with technical applications, which will be the emphasis of this chapter. Knowing the equipment, and trusting what will be produced, is one of the most fundamental considerations an operator makes when selecting to use a camera in the manual or automatic mode for science. The camera can introduce image defects such as image shake or poor image data to name a few.

22.4.1 Manual Mode

Using a camera in the manual mode provides a scientist photographer total control over the photographic exposure and other aspects of image characteristics. There are three components of exposure: (a) the choice of the aperture setting (located on a lens) or in the optical pathway, (b) the duration of time determined by the corresponding shutter speed choice, and (c) the sensor's sensitivity [or ISO] to light. Each setting plays a role in the image's characteristics and will influence image quality.

When using the manual mode, careful attention must be paid to measuring the available light at the sample at the time of photographing. Improper measurements or interpretation of this can lead to an incorrect exposure. Once the light has been measured and confirmed, the photographer must calculate the proper time and aperture choice that will produce a correct exposure. Such exposure will create a file that exhibits detail in the highlights or bright tones and in the dark regions or shadows of a scene. This outcome assumes using a scene brightness ratio that is recordable and can fit onto the sensor using a single time. Using the manual mode will produce significant advantages in the consistency of exposures created across many images. Files produced using the manual mode—when the conditions do not change—will exhibit a high degree of similarity that is useful for batch image processing. When working in challenging environments such as fluorescence light microscopy, using the manual mode facilitates tighter exposure control ensuring the creation of files with detail in the important highlights. Many times the available conditions are difficult to create a perfect exposure and the lighting might require modification when possible to better manage the sample luminance ratio.

22.4.2 Automatic Mode

When operating a camera in automatic modes, the camera will determine some or all of the settings required for the creation of a proper exposure. Sometimes this includes other image attributes as well. When using automatic, the camera will share the correct exposure attributes such as the proper time needed for an exposure, the possible aperture choice suggested for an exposure, where to place the lens' focus, how and where to measure light, the correct white balance, or how to better adjust the camera's sensitivity (*Full Automatic mode*).

Some cameras will have more modes of operation than others. Within automatic operations, a camera can be operated using: an aperture or program priority mode. In the *Program mode*, the camera calculates the shutter speed and aperture setting basing the best choices using a balance of brightness and image stability. Scientific photographers should shy away from the Program mode. There are too many locations where lack of control in this capture mode can lead to a wide range of image variances. *Aperture priority* can be used more effectively in science since the aperture controls the ever-important range of focus. DoF is an important image attribute and a higher priority for controlling than the shutter speed/aperture choice of program mode. A general awareness of the image attributes that come from using long times or with variances in Depth of Field (DoF) will always play a role in choosing one over the other. Never use auto-focusing when making close-up photographs. *Shutter Priority* leaves operator in charge of shutter speed and ISO.

In summary:

(a) *Aperture Priority:* you control the aperture and ISO; the camera sets the shutter speed.
(b) *Shutter Priority:* you control the shutter speed and ISO. The camera sets what aperture to use.
(c) *Program mode*: you set the ISO; the camera sets aperture and speed.
(d) *Full Automatic mode*: the camera sets ISO, speed and aperture.

22.5 Effects of Vibration

Because DSLR cameras use a mirror to see the image in the viewfinder, the physical movement of the mirror and shutter during the exposure can cause image shake. Mirror-induced camera shake will lead to images that are not crisp or clearly delineated. Creating shake can be introduced simply by trigging the shutter. This is outcome is most evident in close-up photography and other applications where the image's size is larger than object's size. When the image size is smaller than object size, such as in wide angle photograph of a group of colleagues, the effects of image shake are difficult to see even if present. When the image size is larger than the object, the effects of camera or environmental vibrations will create images that lack definition and will be easily noticed. One would think to select a shorter exposure time to manage vibration affects, but using shorter shutter speeds can actually increase the apparent loss of image detail from the shutter's mirror. Using longer or slow shutter speeds will actually minimize the effects of mirror shake. When using longer times, the exposure component that creates vibration will be smaller relative to the time of the exposure used to make the base exposure. Using a longer shutter speed can be achieved by reducing the illumination or brightness if image vibration is evident. Using neutral density filters will also allow longer exposure times by taking away brightness and not affecting the color temperature of the light.

Image shake can be introduced by the camera's mirror or from other sources. Elevators, subways and trains, computer fans, or fans located in light sources can all be sources of vibration. Eliminating or dampening vibration should be a high priority for science photographers. Vibration reduction tables are expensive solutions but are excellent tools and very practical for removing vibration. Many, if not all, high-end DSLR cameras will have the ability to lock up the mirror after focusing has been completed. Mirror lock-up is very helpful in minimizing the image shake produced from mirror movements. It might also be practical to trigger the camera using a remote trigger or by tethering the camera to a computer. Using a self-timer for triggering the camera and the delay shutter function is an excellent strategy. Instrument cameras do NOT use mirrors and these types of cameras will not exhibit image shake from the camera itself. All cameras and imaging systems are vulnerable to environmental sources of image vibration.

22.6 Mirrorless Cameras

The simple fact that a camera's mirror and its mechanisms can be a source of camera vibration in pictures has influenced company's interests to make cameras without mirrors for decades. A Leica rangefinder was an early example of a successful camera without a mirror. Mirrorless cameras are called *rangefinder cameras*. Because they have no mirrors, they are quieter to operate; however, the final image and what was observed during framing when taking the photo might not be identical. This condition is called a *parallax error.* Using a mirror and reflex viewing system while requiring space in the camera body creates a precise composition with no parallax error, being what is seen and what is recorded.

Without the need for a mirror, digital cameras can be made smaller and can use various-sized sensors as well. Mirrorless cameras can sometimes create images that are sharper because there is less vibration due to the lack of mirror. One disadvantage of some mirrorless cameras might be the lack of an optical viewfinder. The image is viewable using an electronic viewfinder that can be secured as an accessory or visible on the camera's LCD panel. Composition is accomplished using the LCD display on the back of the camera. This type of camera might be considered equivalent to a compact digital camera but unlike compact cameras, mirrorless cameras can use interchangeable lenses. Compactness, quietness, and possible increased image sharpness are all advantages over compact digital cameras when coupled with the ability of the camera to accept interchangeable lenses. Mirrorless cameras can be used effectively in the laboratory using live view mode. Almost all mirrorless cameras have similar sensor attributes to DSLR cameras. The future looks very bright for the migration of mirrorless cameras in applications where DSLR were traditionally operated.

22.7 Bit Depth

Another important element for collecting the most image information about an object is by increasing a sensor's capture bit depth. A *bit* is the smallest unit of data present in an image. As the basic unit of binary information, a bit can be off and create a zero (0) value or be turned on and create a one (1) value. *Pixel resolution* defines an image's spatial resolution, but a file can also possess color and tonal value resolution. This may be described as the bit or color depth of an image. Imaging applications and devices will always create superior image data with greater bit depth. *Brightness resolution* refers to the number of shades of gray that an image can discriminate and be derived from each pixel. The more bits, the greater the tonal range will be included in the file and this in turn will lead to greater information useful when processing the file to reveal more.

Since sensors have become so good at collecting photons, the ability to discriminate more tones can be accomplished by increasing the bit depth when possible. The term *bit depth* implies that there are a finite number of tones a pixel can manage. Bits are expressed an exponent of 2 and an 8 bit image would be described as 2^8. This bit depth will produce a file with 256 discrete tones for each RGB color for a total depth of 16,777,216 colors.

Contemporary sensors record 8-, 10-, 12-, 14-, or 16-bit images. Increasing the bit depth increases the data available and assists greatly with future image processing. Increasing data may increase a sensor's potential dynamic range but more importantly provides more shades of grays, colors, and data from the object. When a file has more data, more can be made visible or revealed when image processing. Processing data changes the captured data. Sometimes data is improved and at other times it can be diminished because of noise or other artifacts. It can be a trade-off. More bit depth leads to bigger files and more data. Lesser bit depth leads to smaller files and less data. Bit depth can typically be adjusted both at capture and in image processing typically by changing from JPEG to RAW or TIF. When files are down sampled, data is removed, but when files are made bigger, interpolation or false data is created.

22.8 Color Space

An images' *color space* is a mathematical model in which specific colors are recorded, described, and/or displayed. Color spaces describe a set of physical colors and the corresponding names or numbers that have been created to describe them. A PMS (Pantone Matching System) color—a part of the Pantone system color space descriptors—is an example of an analog model, where the highly structured mathematical descriptions were used for color mixing and can be found in the Adobe RGB 1998 color space. sRGB file is also an example of a type of color space useful for preparing images for web or monitor viewing. There are three values used in an RGB system or four values found in CMYK systems.

By carefully selecting a color space, scientific photographers can establish a detailed mapping function used for capturing and processing color and how the color at output will look. This establishes within the mathematical color space an images' color gamut. A gamut of a color will be part of what defines an image. For example, Adobe RGB 1998 and sRGB are two different color spaces and that are both based in the RGB color model. The Adobe RGB 1998 space will display more colors with a wider gamut. sRGB is a smaller color space and will compress or suppress more color information. When deciding what color space to select for a camera, use the widest gamut available located in the camera's preferences. This will lead to files with the most information (Fig. 22.1).

Fig. 22.1 A sensor's ability to discriminate colors and collect sample data is influenced by choice of bit depth and color space. A useful analogy for understanding color space might be found when considering the number of Crayola® crayons found in different sized packages. A package with eight crayons will provide a user with only a fewer colors when compared to a 64 pack. The CIE diagram shared at the bottom shares the approximate the color gamut of sSRGB, Adobe RGB, and ProPhoto RGB. Prophoto RGB leads to the largest files and the most color discrimination. (Image reproduced courtesy of Routledge/Michael Peres)

22.9 Gamma and Contrast

Some instrument cameras allow for the setting of a sensor's capture contrast. No DSLR or mirrorless camera will allow for the setting of a sensor's capture contrast at this time. Adjusting capture contrast would be identified as image gamma and could be found in camera settings. This not typical in a DSLR but is found in microscope and other technical cameras. Gamma is an important contrast characteristic of all imaging systems. It defines the relationship between a pixel's numerical value and the tonal display from the image's actual luminance when displayed. Without using gamma, all of the shades of gray recorded by a camera would not appear as they should and might be described as not having an effective tonal map of an object. Understanding what gamma is and how it works can improve the photographer's ability to create a more accurate exposure useful in subsequent image editing.

Gamma is important for imaging because human vision does not perceive light in the same way as a digital cameras do. Human vision is nonlinear, and a doubling of light—for example—will only make it appear marginally brighter. This lack of separation is increasingly less at higher light intensities. When compared to cameras, human vision is more sensitive to changes in dark tones than changes in bright tones. Gamma and tone mapping is what differentiates human eye light sensitivity to that of the electronic systems. Once the recorded file has been saved as a digital image, the gamma information has been encoded and the tonal values will be displayed more closely to what would be expected by a viewer. Human vision is very flexible, while digital capture systems are not.

Scenes and subjects will contain various brightness or reflectance within them. The difference between a high brightness compared to a region of low brightness describes a scene's brightness range, or *dynamic range*. A sensor can record data more effectively when from a narrow brightness range. A high brightness range creates challenges for a sensor to record the entire range in a single exposure. *High dynamic range* imaging or HDR methods have evolved to manage this problem but are not suggested for science.

22.10 White Balance

In photography and image processing, a photograph's color is the result of global adjustments to the intensities of the recorded red, green, and blue color data or digital information. The ultimate goal of the process remains to render colors correctly. The color of an object is affected by the lighting that is found where the object is located or observed. Human vision compensates for different types of light that leads to white objects appearing white regardless of the light sources of various color temperatures. Digital cameras cannot color correct objects in the same way as the human eye does and require methods to create neutral colors when using different types of lighting to render a white object white. This method of creating neutrality is called setting a gray balance, neutral balance, or *white balance*. When adjusting color balance, there are changes to the overall mixture of colors in an image that are used for color correction and generalized acceptable versions of the image's color balance.

Image color data produced by a sensor must be transformed from the acquired values to new values that are appropriate for color of the light used for capture and subsequent reproduction and display. An image color balance operates in image editing applications usually by directly modifying the red, green, and blue channel pixel values without respect to any color reproduction.

Cameras can set white balance in several fashions using auto or manual or by choosing from several preset choices or custom. Operators can set white balance using the auto mode and the camera will read the scene's various color temperatures and select a setting from its database of pre-programmed choices. This method works well when a scene has lighting that is comprised of one type of light and there are prominent neutral subjects in the scene. The results when shooting the auto white mode are also affected by changes in the lighting. In most cases the most accurate color rendition requires using the manual white balance setting. Manual settings include incandescent, fluorescent, cloudy, electronic flash, open shade, sunny, and custom Kelvin color temperature choices:

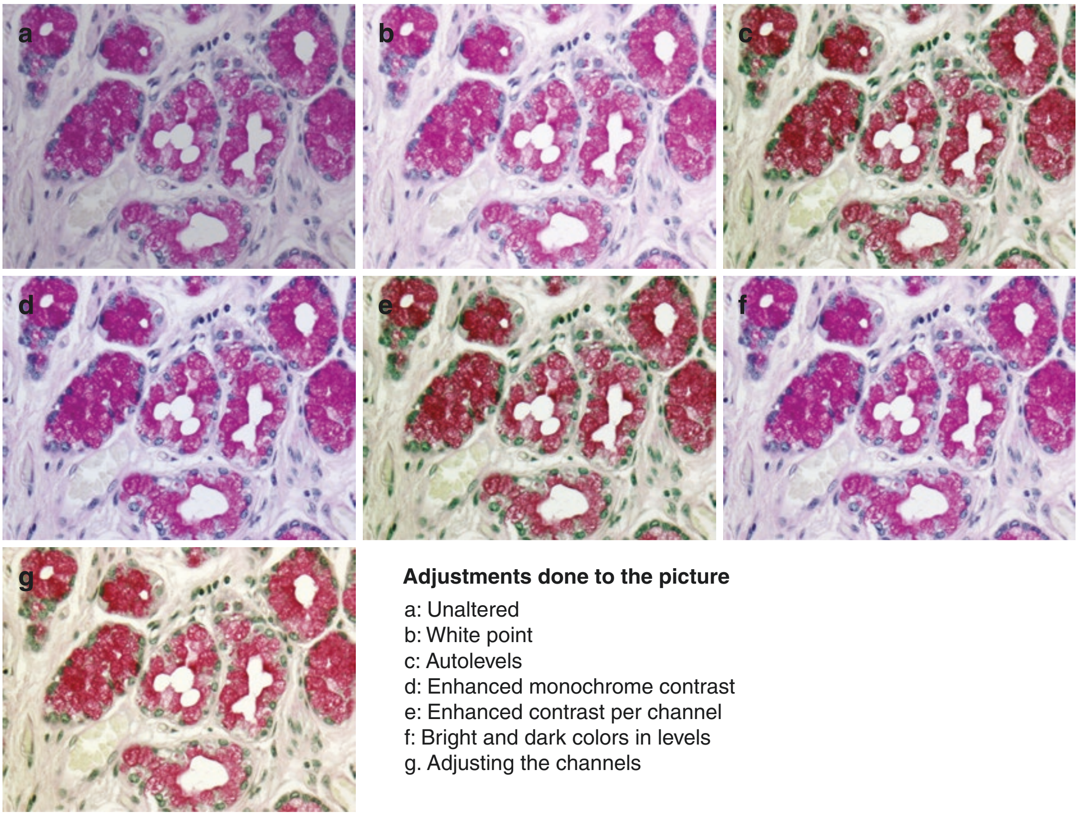

Fig. 22.2 This illustration reveals how an image might look at capture (**a**) and how an image's color display be changed. Setting the proper white balance at capture is a best practice and can lead to a color managed imaging workflow. (Image reproduced courtesy of Jonas Brane/Michael Peres/Staffan Larsson)

- The incandescent setting will be best for tungsten bulbs found in fiber optic lights and photomicroscopes.
- The fluorescent setting will prevent common green casts typical in photographs made using fluorescent room lights.
- The cloud setting will add a bit of warmth to the color temperature.
- The electronic flash setting will add some warmth to the rendered colors.
- The Kelvin color temperature setting is best for total control where the operator sets the degrees Kelvin required to control how the camera will render the hue and intensity of colors in the scene. Using the Kelvin setting, operators can fine-tune the process creating accurate definition and not skewing the colors: it requires a complex knowledge prior to choosing it for usage.

Using a camera in the live view mode will allow operators to see in real time the results of a specific Kelvin color temperature. It can also be useful to locate a white or gray card in the scene to use for white balancing a scene. Some situations such as fluorescence have no color temperature since the spectrum is so finite and contains a single color (Fig. 22.2).

22.11 Capture File Formats

One of the most important decisions a science photographer must make prior to recording camera exposures has to be what file format should be selected for saving out the files. There are a number of file formats available in most cameras. All of the choices have advantages and disadvantages. Decisions about selecting an appropriate file format should be primarily based on which file format will preserve the most data and which one creates the most workflow going forward. One of the first decisions is to choose a format that does (lossy) or does not (lossless) compress captured data. A file format that maintains the full data without compression is called *lossless* and would be a TIF, BMP, or RAW file. There are also formats that offer various degrees of compression or *lossy* such as JPEG, JPEG 2000, or PNG. There is no reason to choose a file format that produces compression at capture because that will compromise the integrity of the file's data right from the start of the imaging process. Data will be changed or lost using compression file formats. There is really only one decision for capturing images in science and that is a lossless format. While many wedding photographers use JPEG because of the advantages for speed and portability of this file format, a science photographer should never use a JPEG file format.

In any type of image file, the size of the file is directly related to the number of pixels, its color space, and its bit depth. Image files can be compressed or they can remain in a file format that does not compress and effectively not changing the captured data. Compression of a file is accomplished using mathematical methods to approximate data or create a facsimile of the original image's data that uses fewer bytes. This process results in the creation of files that are smaller in size than the original captured file. Compressed files can be opened up to their full resolution and in many cases look as they did prior to compression by using decompression algorithms. Considering that, different cameras and software can create different compressions, and it is common for two images with the same number of pixels and color depth to have a very different file sizes when using different amounts of compression. Because of the manner in which pixels, color, and bit depth are evaluated by the algorithms and influenced by the variances in the original image subject, compression can produce different file sizes. Within some compression mechanisms, an image's complexity may also result in smaller or larger compressed file size. This sometimes results in a smaller file size for some lossless formats when compared to lossy formats. For example, graphically simple images such as an image with large continuous color or darkness regions as a background may be lossless when compressed into GIF or PNG formats. These two file formats may result in smaller file sizes than a lossy JPEG format might make.

There are several file formats that save data files that can be used without compression and are ideal for science. These would include TIF, BMP, and RAW. Many instrument (microscope) cameras also have proprietary file formats. Each of these types of files produce saved files that are identical to captured files. This scenario is ideal for science photography. Any compression of recorded data can cause data loss no matter how insignificant. There was a time when storage and storage media were a consideration because they were in short supply and expensive. In this era, that is no longer a concern, and it is critically important to select a file format without compression whenever possible. Proprietary file formats come with one small advantage, and that is all of the capture information from the instrument itself is exported with the file as metadata.

The TIF format is considered by many to be the most universal file format. TIF stands for tagged image file format and produces files that contain data that is structured exactly as the data that was recorded on the sensor. TIF files can be read across all platforms including LINUX, MAC and Windows operating systems. They are also backwards compatible. That is to say, a TIF file can be opened and read using any device regardless of the age of the operating system and the image processing software. TIF files can also be opened using many image processing software packages without special plug-ins. Plug-ins are special pieces of software that are sometimes required to see and read various file types. TIF files will rarely have challenges when used across various platforms, devices, and environments. Most instrument cameras will create TIF files; however, only a few DSLR cameras create TIF files directly.

An ideal file format when using DSLR cameras is the RAW file format. The suffix of RAW file formats will vary across camera brands and might be described as .NEF, .CRW, or others. These file formats save data in an uncompressed manner and are typically opened using a RAW file convertor after capture or using Adobe Lightroom®. RAW files are very useful and provide great advantages over other file types for scientific photography. Their architecture allows more data to be managed and saved allowing for challenging subjects and situations. This in turn creates files that are superior for data collection and preservation. RAW files accomplish this by using file mathematical enhanced structure that allows creation of a greater bit depth and color information to be maintained using the finite exposure range of the sensor. RAW files must be opened and read using a pre-processor program or plug-in called a raw file convertor. This convertor allows the file to be pre-processed revealing more than if the image was processed using Adobe Photoshop® alone. RAW files will be slightly smaller in file size when compared to TIF files. RAW files are ideal in science because they themselves are never altered and the data display changes are shared with the file in an .XMP or sidecar file. If a scientist photographer were ever asked to testify, the RAW file could be re-opened without image processing information by eliminating the side car file (Fig. 22.3).

When using a sensor with a Bayer pattern, neighboring pixels determine how to create the color for all pixels, but when using RAW files, the de-mosaicing process is more “cleanly” handled by the RAW file pre-processor. This leads to more precision and control for the photographic process but can be more time consuming. The bit depth of RAW files is also typically greater. A JPEG or TIFF file is frequently 8 bits per channel at capture leading to 256 tones per pixel color, but it is common for a RAW file to contain 12 bits per channel leading to more than 4000 RGB tones per pixel. RAW file formats are not typically found in instrument cameras at this time.

22.12 Capturing Using Camera Digital Filters

Scientific photographers when preparing to record images must consider whether to have certain attributes of an image file enhanced or reduced at capture. This occurs through the use of various in-camera filters or image modifications. The most common of these “at-capture” attributes would include color reproduction, noise, and sharpening. There are various reasons why an operator would choose, or not to choose use any of these filters. If JPEG files are created, performing some low level sharpening can be helpful but if using RAW, the best practice to de-select sharpening, noise reduction, and color enhancement in the camera.

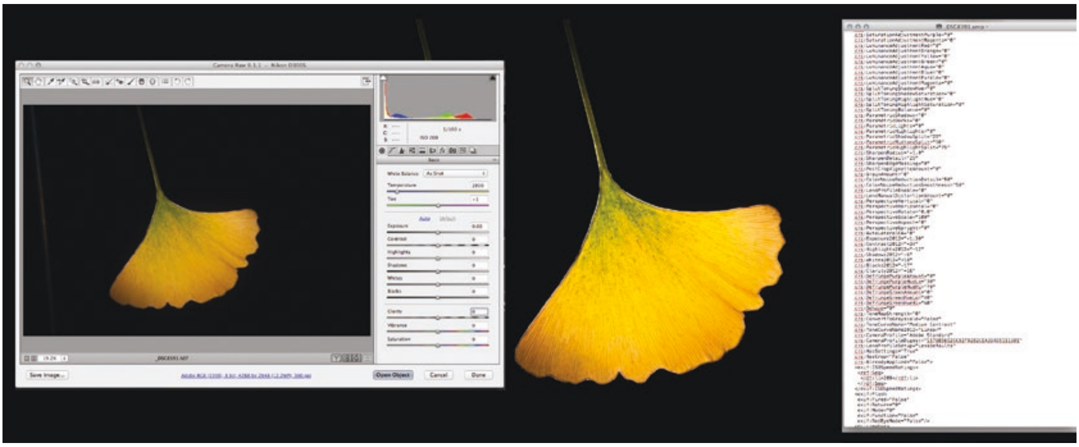

Fig. 22.3 In this figure, a raw file was opened using a RAW file convertor pictured on the left. The center image represents the processed file saved as a TIF file. On the right is the .XMP or sidecar file. Each individual RAW file will have a corresponding .XMP file. (Image reproduced courtesy of Routledge/Michael Peres)

22.13 Sharpening

An RGB camera sensor is manufactured with an IR cutoff and antialiasing filter on top of the Bayer filter on the sensor. While these filters are only a few microns in thickness, they still adversely affect critical image sharpness. In camera, sharpening is an image-processing algorithm. It is sometimes chosen because, like all sharpening tools, it increases the localized pixel contrast. This localized increase in image contrast creates an image's fine details to be more delineated. Having files that are electronically enhanced can sometimes produce digital noise over time when future image processing is undertaken. The initially captured image will typically exhibit a smoother gradient of tonal data per pixel, but when sharpness is boosted at capture, images can appear exaggerated. Creating files that have edge enhancements at capture when blended can appear processed and embellished. Perceptually viewers will respond more favorably to images that are sharp and crisp; however, over-sharpened images will appear as such and may not be well received. In fact they may be described as appearing computer generated.

Different cameras provide operators various levels when selecting to sharpen at capture. A sharpening filter can be applied in an auto-mode or by selecting the amount of sharpening that is desired. It can also be turned off and provide no sharpening at all.

22.14 Working Tethered

Taking photographs when tethered is a technique that has been practiced by photographers for some time. Tethering allows a camera to dialogue with a computer and view digital images both in live view mode and immediately after capture. In the recent past, tethered-shooting was generally reserved for photographers who worked in a studio or on high-end photomicroscopes. Tethering technology has become cheaper and easier to use across all applications.

22.15 Downsides of Tethered Shooting

The ability to preview photos as they are being captured does come with a few downsides. Tethering puts a large drain on a camera battery and subsequently on a connected computer. It is advisable to have fully charged batteries or working using an AC adapter. Also tethering software can be "temperamental." It is not uncommon for tethering applications to simply stop in mid-function. Canon EOS utilizes an excellent tethering software. Capture Integration® software can be used across many brands and supports LiveView function. Adobe Lightroom® will support tether capture but does not support LiveView.

22.16 Tethered Capture Methods

The traditional and most reliable way to connect a camera to a computer is by using a USB cable. There are a variety of different cables and ports available. Some DSLRs and mirrorless camera possess built-in Wi-Fi or can be operated using wireless tethering.

22.17 Macro Lenses Are Required for Close-Up Photography

Almost any camera with the right features can be used for close-up photography, but using a macro lens (on the camera) is the most critical element needed to produce the best outcome. Many relatively inexpensive compact digital cameras are fitted with zoom lenses that are adequately corrected for moderate close-up use, despite being designed primarily for use at the infinity focus. This capability is possible because of the digital viewfinder, which bypasses the reflex viewing arrangement required in DSLR cameras. Smartphones have also become common tools for making adequate close-up pictures; however, DSLR or now mirrorless cameras can use of variety of close-up or macro lenses both in fixed focal lengths and zoom lens types as well. These lenses will create excellent and well-defined

Fig. 22.4 This figure includes three different lenses that can be used for close-up or macro work. A Canon 24–70 mm macro zoom is featured on the left, Canon 50 mm prime macro lens in the middle and a Canon 65 mm macro on the right. They have all been designed for different applications and should not be considered equal but do allow for close up applications. (Image reproduced courtesy of Routledge/Michael Peres)

images. A zoom lens with close-up capability is often described as macro zoom. It can create very useable results but a single focal length close up lens is vastly superior for close-up applications. A prime single focal length macro lens will make better photographs than a macro zoom lens (Fig. 22.4).

Important optical characteristics are designed into macro lenses including excellent edge-to-edge image definition using a medium aperture setting. They have been highly corrected for color and spherical aberrations as well. Their most important feature is their ability to produce edge-to-edge performance when photographing at small working distances. This capability is called flat field or PLAN. So while these lenses are called macro, they are actually close-up lenses and reduce image size. True macro lenses are designed to produce magnifications of 1:1 or greater and used in situations where the lens-to-sensor distance is greater than the lens-to-subject distance. This is no longer common for image makers (Fig. 22.5).

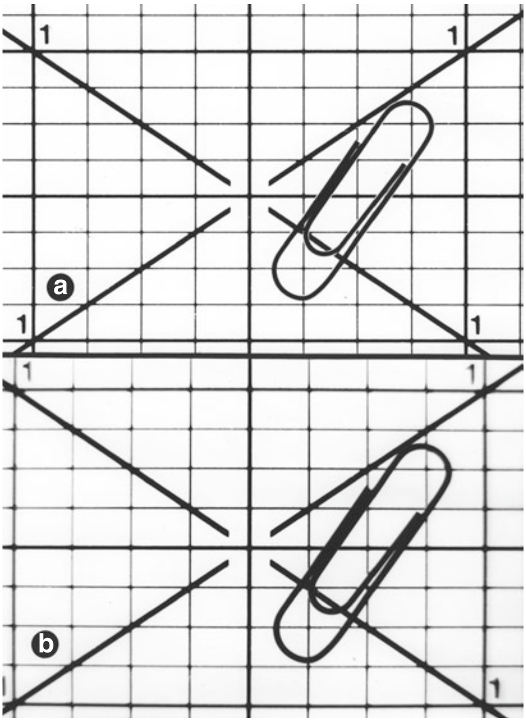

Fig. 22.5 This composite photograph reveals the differences between a 50 mm normal lens on the bottom (**b**) and a 50 mm macro lens (**a**) on the top. There are considerable quality differences in the edge-to-edge definition of the image structures such as lines and contrast. (Image courtesy of Routledge/Michael Peres)

Expensive macro lenses have elaborate internal mechanisms that allow groups of lens elements to move independently as the lens focuses closer by extending or shortening for various working distances. Almost all macro lenses can produce excellent life-size (1:1) or slightly larger images. A terrific feature of close-up lenses is that they have reproduction ratios inscribed on the barrel, have fairly modest maximum apertures, and come in various longer—and other than a normal—focal lengths

Fig. 22.6 In this photograph, the reproduction scale on a Nikon 60 mm lens is highlighted. This lens can create a magnification range from 1:1 through a 1:10 lifesize. The corresponding reproduction range is established by positioning the magnification adjacent to the 1: in the focusing window. (Image courtesy of Routledge/Michael Peres)

producing larger subject to lens distances when operated at 1:1. Depending on manufacturer, common focal lengths can be 50 mm, 60 mm, 100 mm, or 200 mm with a maximum aperture frequently of *f*/2.8 (Fig. 22.6).

When images are being made at a 1:1 magnification or life-size, both the working distance and the image distance will be equal to twice the focal length of the lens. Longer focal lenses provide increased working distances and can be helpful when creating effective lighting or can become important when it is not wise to be near to things such as heat or infectious diseases. So a 100 mm lens will be placed 200 mm from the subject when making a 1:1 photograph. This can be helpful in medical applications or with potentially hazardous materials. Longer working distances might not be ideal for laboratories because of the longer working distance and limited space. Longer working distances can be challenging when making a setup or adjusting lighting which is just out of reach of the operator. Longer focal lenses do not create less DoF when compared to shorter focal length lenses used to create images of the same magnification.

22.17.1 Getting Closer: Supplementary Lenses

Sometimes there is a need to get closer and focus at shorter working distances than a macro/close-up lens is capable of producing. This problem occurs because most fixed focal-length camera lenses are optimized for long camera-to-subject distances and they are usually are limited in their ability to work at short focus distances. This distance can be reduced and the image size increased by using supplementary or close-up lenses. These lenses were sometimes called *plus lenses* or *diopters*.

Using a threaded supplemental lens on a fixed focal length actually reduces the primary lens's focal length. This in turn allows the lens to focus at a shorter distance. The magnifying potential of supplementary lenses increases as the diopter number increases e.g., +1, +2, up to +20. So a +20 supplement lens will magnify an object more than a +1 lens.

This distance can be reduced and the image size increased by using a supplementary or close-up lens. A close-up lens is a high-quality simple magnifying lens. These lenses will either be a single lens or an achromatic doublet that attaches to a lens like a filter. These lenses are sometimes called *plus lenses* or *plus diopters*. Using a diopter is the easiest way to achieve close-up images. It is always best to attempt image creation without the addition of lenses when possible since any additional lenses to a primary lens can degrade optical performance. The optical power of supplementary lenses increases as the diopter number increases, for example, +1, +2, up to +20. The diopter number of a lens is the reciprocal of its focal length in meters which is expressed:

$$D = 1000\ \text{mm} / f \text{ or } f = 1000 / D \quad D = \frac{1}{f} \text{ or } f = \frac{1}{D}$$

So, if using a +2 close-up lens on a focal length of 0.5 m (500 mm), the lens will have a focal length of 0.20 m (200 mm). Alternatively, it is possible to convert all values to diopters and then convert their sum to focal length. For example, a 50-mm lens has a power of 20 diopters. Add a 2+ supplementary lens and the sum is 22 diopters. The combined focal length is 1000 mm divided by 22, or, about 45.4 mm.

If it is necessary to determine the total focal length of the camera lens combined with a supplementary to calculate the lens-to-subject distance, use the following common lens equation:

$$u = \frac{v - f}{f}$$

where u is object distance and v is image distance.

Supplementary lenses can be combined to obtain even greater magnification; however, when combining close-up lenses, the strongest should be closest to the camera lens. Image degradation will increase dramatically when more than two supplementary lenses are combined. Supplementary lenses can also be used in combination with extension rings and bellows in order to minimize the total amount of lens extension. Shorter lens extension produces shorter exposures. Shorter exposures may, for many subjects, offset the theoretical advantage of using a camera lens with extension tubes alone. Using a small lens aperture may minimize the aberrations introduced when using simple, positive close-up lenses.

22.17.2 Using Teleconverters to Get Closer

Teleconverters are useful precision optical accessories that can be mounted in-between compatible lenses and the camera body. Teleconverters increase the focal length of the primary lens and can produce a shorter working (object) distance as well. A teleconverter used in combination with a 200-mm close-focusing lens, for example, will yield a life-size (1:1) image while maintaining a 71-cm (28 in.) minimum object distance. This amount of working distance is advantageous for many biomedical, industrial, and natural history applications. An increased working distance allows for considerable freedom in arranging lighting or keeping a safe distance from an event or subject that is pathogenic. Teleconverters have optical elements and can degrade the resolution of the primary lens if not of a high optical quality.

22.17.3 Another Way to Get Closer: Extension Tubes

Cameras with interchangeable lenses also allow for *extension tubes* or a bellows to be inserted between the camera and lens. This extends the lens–image distance. Increasing the image distance rather than changing the focal length produces a better optical result than using supplementary lenses when creating low magnification photographs. Extension tubes are cylindrical tubes of various lengths, used singly or in combination to change the reproduction ratio or image size in fixed steps. Tube lengths may vary from 5 to 100 mm, and extensions of 250 mm or more can be used. They are fitted together with threads or bayonet-type mechanisms, and some allow the camera's automatic diaphragm features to be maintained but typically camera lens must be operated in a manual mode. Extension tubes allow one single lens to create magnifications greater than 1:1.

Extension tube sets are relatively inexpensive but are a bit inflexible because they come in specific lengths. This shortfall can be overcome by using a bellows. A bellows is more costly but is essential for professional work because it allows precise control over lens–image to distances, which results in more choices and precise in creating image magnification.

When using extension tubes or bellows for close-up work, ordinary lenses should not be used since they are not well corrected for short working distances or they are not corrected for flat field applications. A common or normal camera

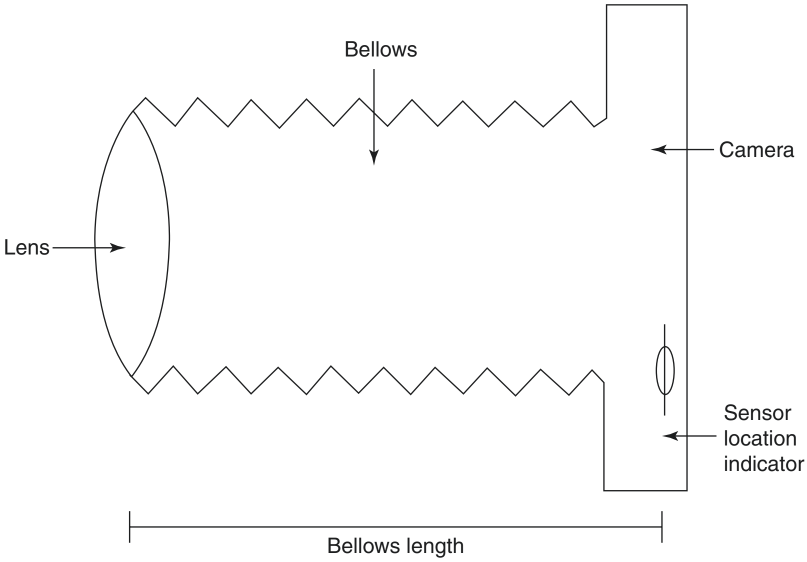

Fig. 22.7 The basic parts of a close up and photomacrography system include a close up or macro lens, a bellows (or extension tubes), and a camera. (Image courtesy of Routledge/Michael Peres)

lens has been corrected for long object-to-lens or working distances and uses typically a short lens-to-detector distance. When this type of lens is used with short working distances, the resultant photos will not be optimal since there are numerous aberrations that will become enhanced when used with short working distances. Optical performance can be markedly improved by using the normal camera lens reverse mounted, so that the rear element of the lens is closest to the subject. Manufacturers supply reverse mounting rings for this purpose, but all of the lens's automated features will be disabled. A true close-up lens remains the best optical solution for use in this image size range (Fig. 22.7).

22.18 Focusing, Depth of Field, and Diffraction

To achieve a specific image size in close-up photography using a DSLR camera, traditional techniques will need to be abandoned. To achieve critical focus in close-up work, the required reproduction ratio should be determined and (if available) set on the lens barrel. The camera can then be focused by changing the working distance only. This involves moving the subject or camera closer, or further from one another. This may be done precise by using a focusing rail. A good rail may have calibration marks and smooth adjustment slides and will lock for precise control over its movements. The rail should be attached to a tripod to facilitate the most robust structure and create the most precision of outcomes.

A lab jack or other stages can also be a useful tool for achieving precise control over where focus is placed. A quality lab jack is preferable to an inexpensive one. There will be side-to-side movements when the height adjustment is made using inexpensive equipment, and this movement will cause minor changes to the photograph's composition. Moving the camera can also be accomplished by adjusting the height of the lab stand or tripod up and down.

If a lab jack is not owned, often an old lens can serve as a lab jack used for focusing. Since the helical focusing mechanism in a lens behaves much like a focusing rail, adjusting the lens focus will move the sample up and down. It is important to try and "lock down" the lens's base to avoid it moving around on the table. You can use a large "C"-clamp on the base of the lens to add weight and limit shifting when in use (Fig. 22.8).

The range of sharp focus in a photograph is referred to as its *depth of Field* (DOF). DOF assessment can be a bit subjective and viewer dependent, but in close-up photography, depth

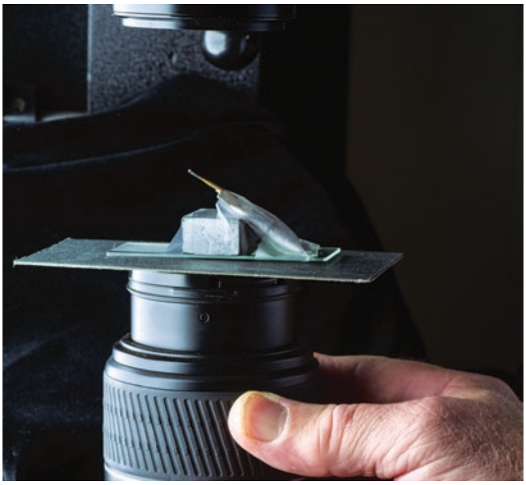

Fig. 22.8 Changing the working distance can be accomplished by moving the sample or moving the camera. It is important not to change the reproduction ratio on the lens. A lens can be used as a lab jack. Because of the smooth helical focusing mechanism in a lens, small changes in working distance can be changed very precisely. It can be useful to cover the top of the lens with a piece of black cardboard as evidenced in this illustration. (Image courtesy of Routledge/Michael Peres)

of field will be noticeably small, and becomes smaller still with increasing magnification. In everyday photography, an image's depth of field can be increased by using a small aperture. As the magnification of 1:1 is approached, a very small aperture—*f*/16–*f*/22—will produce diffraction that softens image crispness. Diffraction affects are dependent on a sample's characteristics and magnification. In general photographic applications, there tends to be more depth of field behind the subject than in front. In close up photographs though, the distribution is more equal in the front of—and behind—the subject. DOF can also be increased using Z stacking software or increased DOF imaging.

22.19 Creating Camera to Subject Alignment

Since the DOF in close up photography is shallow and there is a short working distance, it is useful to align the camera to the sample's principle plane of interest to maximize what DOF is available for recording. Once the reproduction ratio has been set on the lens, the camera should be aligned to the subject. Either the camera or the subject can be adjusted. When focusing, it is important to move the focus into the sample when working in this way. DOF can easily be wasted in the space above the sample. Using a spirit or electronic level can also be useful to ensure all surfaces are parallel. This will create the maximum DOF possible produced by a lens' aperture choice and effects of magnification (Fig. 22.9).

22.20 Selecting the Best Aperture Possible

Camera to subject alignment will play a role in the range of focus, but so will the DOF created by an aperture. Using a small aperture will increase the zone of focus but can also introduce diffraction as the image size increases. Diffraction will make images appear soft. Using an aperture that is too open will produce a shallow focus (Figs. 22.10 and 22.11).

22.21 Exposure Compensation and Determination

When increasing the sensor to lens distance, light will be lost in the camera and an incorrect exposure will be created. When using today's sophisticated cameras, the information required to calculate the corrected exposure resulting from light loss can be accomplished by the camera's meter without effort. As image magnifications increases, the amount of light reaching the detector from a given area of the subject is correspondingly reduced when using extension tubes, close-up lenses, or a bellows. Exposure evaluation using *Through-The-Lens metering* (TTL) equipment is straightforward. It should be chosen if the system permits. As an example, at a 1:1 magnification, the rear element of 50-mm lens may be up to 100 mm from the detector. At this reproduction ratio, there will be two stops of light loss in that lens. The amount of light loss for any

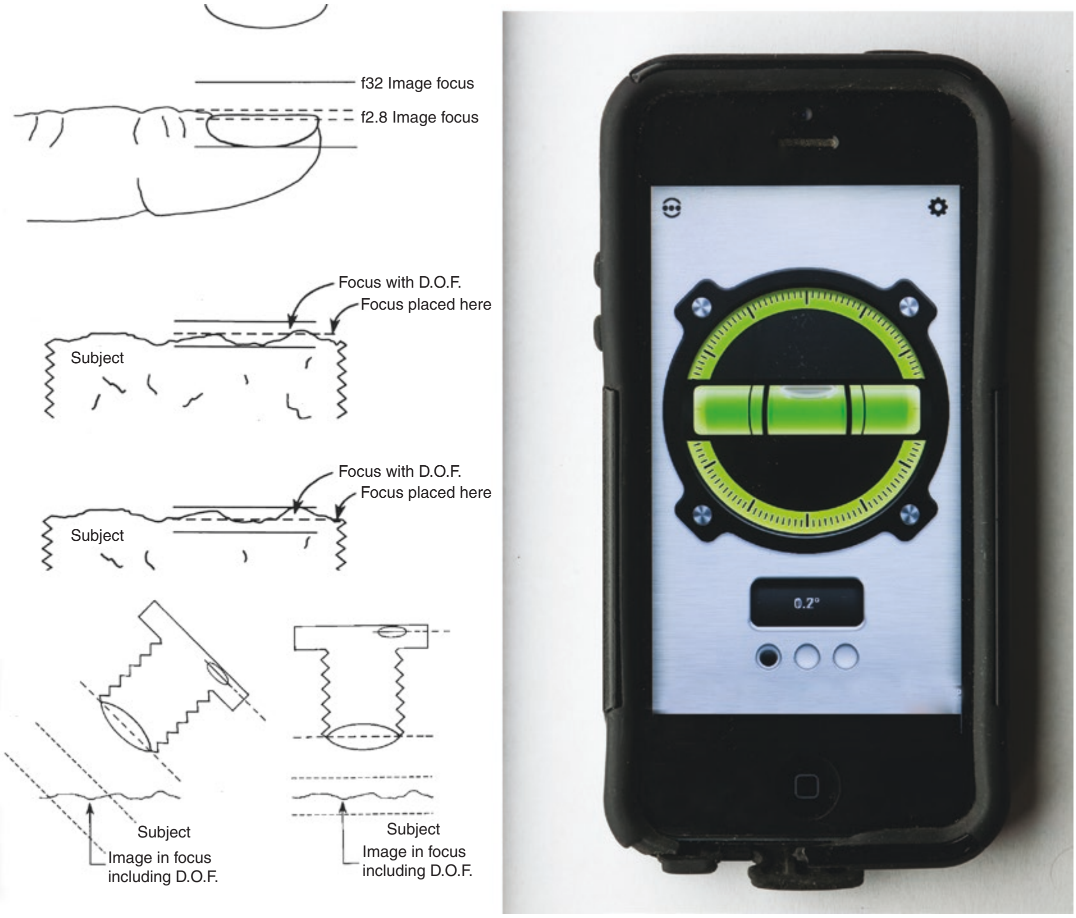

Fig. 22.9 Creating and maintain an adequate DOF in close up and macro applications can be a challenge. Using an appropriate aperture can be most helpful. In the example illustration, the zone of DOF can be increased proportionately by using *f*/32 rather than *f*/2.8. Additionally rolling the focus into the sample rather than placing it on the top of surface can increase by a small amount the DOF. One of the most important tools is alignment camera to subject alignment. Keeping the sensor parallel to the sample surface can be one of the most effective of all three strategies shared in this graphic. On the right is an image of an app from a Smartphone for a level. A level can be a useful tool aligning the camera to the stage. (Image courtesy of Routledge/Michael Peres)

reproduction ratio can be calculated. There are several equations that can determine the exposure factor.

22.22 Making Images that Are Larger than the Object

Photomacrography is usually defined as having image magnifications in the range of 1:1 (life-size) up to about 25:1 (25 times life-size), but this subject is more aptly defined by the equipment used to create this magnification. Photomacrography equipment is generally more elaborate and complicated than the equipment used for close-up work. In photomacrography, the lens is further from the sensor than the lens is from the subject.

There are several ways to produce magnified images or photomacrographs including using a simple microscope, which its single stage of magnification or magnifying lens. The best lenses for macro are those designed for this purpose and have special features that will be shared

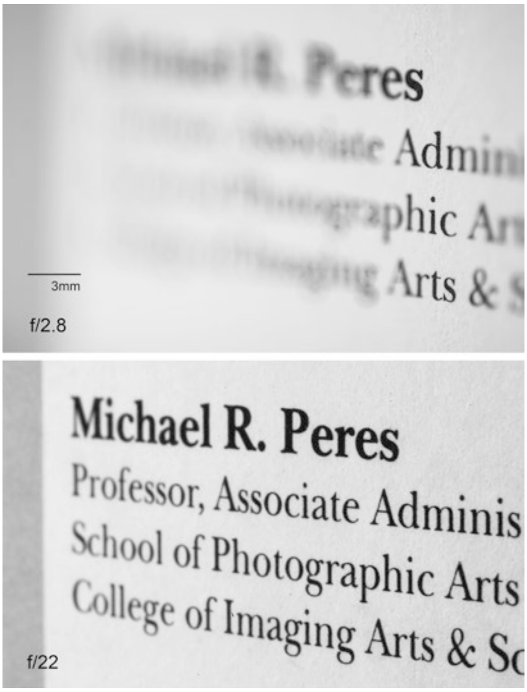

Fig. 22.10 This photograph features a business card where the minimum and maximum DOF possible was formed using a magnification of 1:1. The top photo used an aperture of *f*/2.8 and a bottom *f*/22. (Image courtesy of Routledge/Michael Peres)

below. These lenses are used with a bellows or extension tubes and lead to images that are larger than the subject. There are very few if any true macro lenses still made by any manufacturer. Many close-up lenses will achieve 1:1, but only the Canon 65 mm macro lens creates magnification all by itself. Most of the photographic work done in this magnification range is accomplished using a stereomicroscope. Some scientist photographers will also try to use a compound microscope using a 1× or 2× objective with varying degrees of success. The resolution of these objectives used on a microscope will be very low. When making magnified images, the object is placed at a distance equal to the focal length of the taking lens. Additionally, the image must travel a distance to the detector that is greater than two times the focal length of the lens to create magnification.

In this magnification range, it is essential to have a rigid camera support for the components, ideally equipped with some means of moving each element (object, lens, and detector) precisely along the optical axis and being able to secure the camera parts firmly. This is why photographs in this magnification range are often made with low-power stereomicroscopes instead. Stereomicroscopes will often have a zoom objective lens and possess a relatively low numerical aperture. These instruments are excellent for use with longer working distances and usually equipped with rack and pinion adjustment of object distance improving the fine focus; however, photographers should be aware that the tilted optical axis necessary used in stereomicroscopes results in making photographs that have a similarly tilted depth of field. A binocular or compound microscope does have two eyepieces, but will not produce stereo images directly.

22.23 Bellows and Laboratory Setup

A bellows is, in effect, a variable length extension tube with a lens board at one end and a location for the camera to be attached on the other. The camera and lens boards will be mounted on some sort of a focusing rail system. The bellows extension can easily be adjusted over a very wide range to achieve the correct and precise magnification for the sample under evaluation. Magnification will be limited by the rail's length and the focal length lenses that are available. A bellows is a seemingly simple piece of equipment to operate but it often causes problems for photographers, mainly because the spacing of the key elements (detector, lens, and subject) are not fixed, which means that working distance, magnification, and focus are independent and interdependent. In a "normal" camera, two of these three variables are usually fixed. Although some bellows can accept a wide variety of cameras and lenses, many are designed for specific manufacturers' lens mounts.

Fig. 22.11 A close-up lens looks very different than a true macro lens. On the left is a Nikon 60 mm lens and on the right, three Zeiss® luminar macro lenses with focal lengths of 40 mm, 25 mm, and 16 mm, respectively. Notice the macro lenses have no focusing collars, only an aperture adjustment ring. The lenses relative working distances are indicated in this graphic. (Image courtesy of Routledge/Michael Peres)

22.24 True Macro Lenses and Optical Considerations

A laboratory photomacrography camera system described above will usually accept a wide range of apochromatic macro lenses optimized for specific magnification ranges but versatile enough to be used with a true compound microscope and eyepieces. This link between micro and macro endured for many years and these type of macro lenses often used RMS (Royal Microscopical Society) treads used for mounting rather than a bayonet.

True macro camera lenses are special-purpose lenses designed for magnifications greater than infinity. These lenses may have other names reflecting their size, such as short mount, or sometimes called *thimble lenses* because they look like a thimble. Macro lenses are unlike close-up lenses in several respects. The first and most obvious difference is a macro lens has no focusing collar because the lenses are designed for use on a bellows. Consequently most macro lenses will have only a lens diaphragm ring and focus is controlled through changing the working distance as function of the pre-determined bellows length. The aperture range is usually smaller than for traditional lenses used for other technical purposes. True macro lenses will typically have maximum apertures of *f*/2.8 and minimum apertures of *f*/l6 or at its smallest *f*/22. At high magnification, small apertures produce undesirable diffraction effects and poor resolution and are rarely selected.

The diaphragm rings of macro optics are seldom marked with conventional *f*-numbers. The *f*-numbers on ordinary camera lenses are defined in terms of an object photographed at infinity, which is never the case. These lenses work at short lens-to-subject distances. The effective *f*-number therefore increases as bellows extension increases. For this reason, some macro lens diaphragm settings are designated by a simple numerical sequence, for example, 1, 2, 3, 4, 5, 6, where each number is a factor of 2 which creates a one-stop exposure value difference. Other lenses use Stolze numbers, which are similar to *f*/stops where each number 1, 2, 4, 8, 15, 30 is proportional to its adjacent stop by a factor of 2.

22.25 Other Lenses that Can Be Used for Magnifications 2:1 and Higher

Different manufacturers, such as Carl Zeiss®, Nikon®, Leitz®, Canon®, and Olympus® produced true specialized macro lenses of excellent quality in the past which are no longer manufactured. As previously mentioned, Canon makes a special lens—a 65 mm macro *f*/2.8—that creates an image range of up to 5:1. It is very sharp and very useful for creating image sizes that are larger than object sizes. Regrettably it is not possible to use this lens for samples that need to be reduced in image size or less than 1:1.

Camera companies are no longer making true macro lenses, but they may be still found as used equipment or on eBay®. Perfectly serviceable lenses made by Bausch & Lomb® or Wollensak® lenses might also be found there as well. Also, as a consequence of the evolution from motion picture film to video cameras, wide-angle and normal focal lenses used for 16-mm cine cameras can easily be found and adapted for use in this magnification range. The 16-, 25-, and 50-mm lenses work well for photomacrography when reverse-mounted. Reverse-mounted cine lenses are not as well corrected as true macro lenses, but they can make a satisfactory "poor man's" substitute.

22.26 Setting Up the System

1. It can be useful to determine the sample's magnification needs to start and then compare the object size to the sensor size. Predicting magnification is quite simple. When using a full sensor DSLR camera, the sensor will be 35 mm or 1 in. in the long dimension. Magnification requirement can be calculated using the equation

   $$M = i / o,$$

   where the sensor represents the image and the object will be measured. For example, if a sample were 5 mm, 35 mm/5 mm would require an image magnification of seven times to be produced.
2. The best way to calculate the magnification of a single lens system is by using the equation

   $$v = \left(m+1\right)F$$

   where *v* is the image distance, *m* is the magnification of the system, and *f* is the focal length used. This equation can be used effectively for magnification calculations in close-up photography or photomacrography, independent of the format of the camera system utilized.

   Using the example shared about, approximately 7× is needed. Start by selecting a 25 mm or 1 in. lens. Substituting 7 for the magnification and 1″ for *f*, a bellows length of 8″ or 200 mm would be required.
3. Using a 1-in. lens creates 8 in. of separation between the lens and camera sensor. The sen-

sor's location can be determined by locating this insignia found on the camera body.

4. Place the subject at a distance of one focal length or 1-in.—in this example—from the lens and change the working distance to focus the image. Do not change the bellows length.
5. The camera can be operated in a tethered or live mode and the exposure can be assessed in the preview window. The amount of light loss in the system can actually be calculated using the method shared before.
6. Focus by changing the working distance.

22.26.1 Exposure Compensation

As the lens is moved further from a sensor required to increase magnification, significant light loss will occur. This principle is defined by the inverse square law of illumination. A camera with an internal metering system will automatically adjust for the light loss. Some events cannot be re-photographed and require establishing settings before beginning to work with a specific sample. Some meters for scientific applications have sufficient sensitivity to make readings using the viewfinder, which would automatically compensate for the loss of light in the system. The light loss in a macro camera system is referred to as the *bellows factor* and should be applied to the metered reading necessary to obtain a correct exposure whenever light is being measured by using an external tool.

22.26.2 Exposure Factor Equations

There are several equations that can be used to determine an exposure factor, but the two most widely used are:

$$\text{Exporsure factor} = \left(\frac{\text{Image distance}}{\text{Focal length}}\right)^2$$

This following equation is equivalent to the previous one because the image distance is the lens focal length plus any extension, making then the equation:

$$\text{Exporsure factor} = \left(\frac{\text{Extension}}{\text{Focal length}} + \frac{\text{Focal length}}{\text{Focal length}}\right)^2$$

but extension/focal length is equal to R, and the second term is 1, brings us back to:

$$\text{Exposure factor} = (R+1)^2 .$$

The $(R + 1)^2$ equation is easier to use if scales or rules are substituted in the specimen plane needed to determine reproduction ratio. The (image distance/focal length)^2 version is easier to employ if a graduated bellows is used to determine image distance (remember to add the focal length to the bellows extension reading to get the entire image distance if the bellows scale reads "0" at the infinity focus position). The exposure time indicated for a selected *f*/stop with hand-held exposure meter is multiplied by the exposure factor.

22.26.3 Depth of Field

The DOF is the distance in front of and behind the object that is considered to be in acceptable focus in an image. In magnified images—there is relatively speaking—no DOF in a photograph. The depth of field will increase as a lens is stopped down, but unfortunately there is a fundamental limit as to how much a lens can be stopped down without degrading the image, even in the plane of sharpest focus. This softening is the effect of diffraction caused by the bending of light as the light passes through a very small slit or opening. This leads to a lessening of image sharpness.

Resolution of an image is assumed to be diffraction limited, and points found at either side of the specimen focal plane will be blurred by the combined effects of optical and diffraction blur. Subsequent larger magnifications will be more affected. In practice, any aperture can be used when magnifications are less than ×5, but as the magnification goes beyond that, image degradation becomes obvious both in the viewfinder and on the subsequent print. In theory, all lenses will form their highest resolution when operated wide open or at their maximum open-

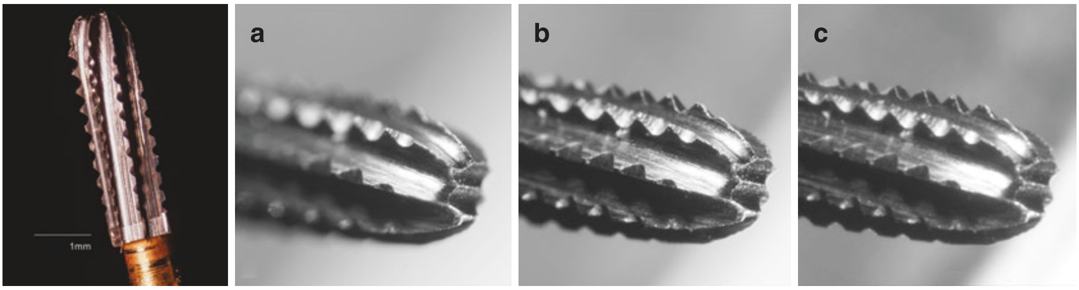

Fig. 22.12 This illustration reveals the DOF and sharpness of a dental drill burr photographed with a magnification of approximately 5×. Photograph (**a**) was made with the lens wide open at *f*/2.0. It shows the lens' least amount of DOF and most resolution. Photograph (**b**) was made at *f*/11 and reveals a modest gain in DOF at no real expense to resolution. Photograph (**c**) used the lens's smallest aperture, *f*/22, and reveals what happens to an image's sharpness, negatively impacted by aperture-induced diffraction. On the flip side, there is a considerable increase in DOF. (Image courtesy of Routledge/Michael Peres)

ing, for example, *f*/1.4. There are other factors though such as optical contrast and related optical characteristics of an image (Fig. 22.12).

22.27 Stereo Photomicroscopes

Stereomicroscopes seem to have replaced almost all photomacroscopes in science laboratories. It is truly rare to find someone still using a true photomacroscope for low magnification work. Stereomicroscopes are faster to use and are certainly more flexible than macro systems. They provide a range of magnifications, and they can quickly be adapted for use with both translucent and opaque objects.

A stereomicroscope is quite different than a compound or upright microscope. It has a primary objective and eyepieces, but this is where their similarities end. Stereomicroscopes do some things very well; however, they are limited for other reasons. One of the greatest advantages for selection of a stereomicroscope separate from its ease of operation is that the image is oriented correctly to the way it is seen: the left side of the object is the left side of the image. When moving an object or dissecting the object, this orientation alignment can greatly simplifies its use. This makes this instrument ideal for dissection, surgery, and manufacturing where operators can focus on the work and not swapping an orientation. For all other magnified imaging systems, the image and the object are opposite in orientation to one other. If there is a piece of dirt on the left side of an image of a sample when looking into the eyepiece using a compound microscope, the dirt is actually on the right side of the sample. Because of this, an operator must constantly remember this reality especially when working with delicate materials that can be damaged by handling or moving.

Stereomicroscopes form two optical images because there are two optical pathways in a stereomicroscope that create two different points of view for a viewer. This allows the image from a stereomicroscope to produce true stereopsis or stereovision. The observed image produced from a stereomicroscope is said to be 3D. The stereomicroscope is typically located on a vertical column that is adjustable. This adjustment allows the microscope to be used for evaluation of objects of various thicknesses. The instrument can be quickly raised or lowered on the column, and the objective's working distance can be quickly changed.

There are two basic adjustments on a stereomicroscope. One adjustment mechanism is used for focusing or changing the working distance of the microscope and the other is for changing the microscopes magnification. The focusing knob moves the instrument up or down using a very precise gear system. Unlike compound microscopes where the sample is moved, the stereomicroscopes itself is moved. There is only one focus mechanism for a stereomicroscope, not like compound microscopes where there is a fine and coarse-fine adjustment. A stereomicroscope sometimes also uses a Barlow lens. This lens will increase working distances and decrease magnifications.

There are actually two ways that magnification is adjusted in a stereomicroscope. The initial magnification is dependent on the microscope's primary objective. Many stereomicroscopes have various primary objectives such 1×, 1.5×, or 2× as the first stage of magnification lens. These lenses are interchangeable. This objective lens forms the initial stage of magnification. Then it is possible for a magnification adjustment function specific to the instrument. Many stereomicroscopes have a zoom range of approximately 10:1 times. This adjustment is not fixed and allows an operator to have an entire range of fine adjustments available to optimize just the right amount of magnification. The viewing eyepieces also have magnification. These can range from 2.5× to 10×. When all the various components of a stereomicroscope are factored as possible elements, these instruments can create images with a magnification of 2× times up to 250×.

Stereo is achieved as a consequence of the two optical pathways; however, the imaging system utilizes only one of these pathways. An image produced from a stereomicroscope is not stereo. In fact, since the lenses by design are not at a 90° axis from the sample, there can be some minor challenges to manage imaging and imaging outcomes. Each objective is offset approximately 6° from 90° producing an off axis view from left and right side of the object. When imaging, the image is formed from a slightly offset point of view. This can be easily addressed by positioning a sample at a similar angle of approximately 6° away from the perpendicular axis when the sample is underneath the objective lens.

The offsetting of the imaging lens can create minor aberrations since by design the lens is not optically centered over the sample. Because of advances in lens design, corrections and higher numerical apertures are more common in stereomicroscopes than in years past.

22.28 Photographing

There are no real unique challenges associated with making photographs or video using a stereophotomicroscope. There will be a beam splitter located in the instrument, which directs a portion of, or all, of the image to the camera. The image in the camera will be dimmer than the image observed in the eyepieces since rarely will 100% of the image brightness be directed there. There will always be some light loss in an image when relayed to the camera and away from the viewing eyepieces. Often the image will remain visible in the eyepieces, but the focus may be different. Many stereomicroscopes have an iris diaphragm located in the optical pathway. Unlike the aperture diaphragm of a compound microscope, the iris diaphragm will have limited influence on an image's depth of field. Like all diaphragms, this iris diaphragm will also remove light intensity from the system, which lengthens the exposure times. One of the limiting factors when using a stereomicroscope can be the objective's numerical aperture (NA) when compared to a compound microscope's objectives of similar magnification, or a true macro lens. Not all images made from lenses of similar magnification will be equal (Fig. 22.13).

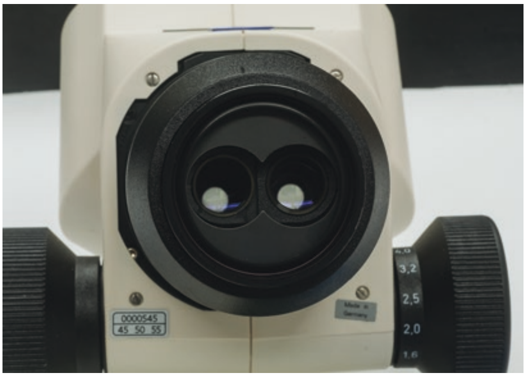

Fig. 22.13 This illustration reveals how two imaging pathways are formed within the microscope. Located behind the primary objective are two optical pathways that see a sample at small angles. The two images produced by the two lenses are offset by approximately a total of 10°–12°. (Image courtesy of Routledge/Michael Peres)

22.29 A Primer for Lighting Small Laboratory Subjects

The technical elements of radiated energy behaviors—and light—are well known. There are countless textbooks written describing the physics of radiated energy. Brightness, color temperature, and other characteristics of light are often described in technical literature using a scientific point of view. Creating effective lighting for science is more than simply having a technical knowledge about radiated energy and related behaviors. There is light, and then there is lighting. Creating effective light for scientific photographic documentation does not have to be an overly complicated challenge. Using some basic equipment in conjunction with some practical strategies can lead to surprisingly good outcomes.

It is possible without great knowledge in photographic lighting to produce adequate results, but very often, artificial lighting photographs will look more like amateurish snapshots produced by the uninitiated. Many times the on-camera flash will be part of the solution or problem. The short working distances associated with close-up photography in conjunction with electronic flash lighting leads to the creation of very direct and harsh (contrast) light. The subjects in pictures illuminated with direct flash using a short working distance will display very “white” whites that have NO detail and black harsh shadows, also without detail. Ambient room lighting can also play a role in creating “not so effective” lighting for some subjects. Bad lighting leads to bad pictures. It’s just that simple. Good lighting makes the characteristics of subjects visible and can make the nearly invisible, visible. This is the ultimate goal of good lighting required for and used in scientific photography.

Photography by definition is writing with light and describes one of the most fundamental components needed to make a good photograph. Effective lighting reveals characteristics of a subject. In the fine and applied arts, effective lighting might reveal a mood or a concept. It may emphasize a time of day, or sometimes the light itself might become the subject of the photography.

For science images though, using artificial light needs to be carefully considered. Science photographs need to be first and foremost about scientific data and not about an interpretation or bias about a subject. Science photographs need to exhibit neutral points of view. Because photography is a continuum of events that leads to the production of images, what type of lighting is created is one important element of that process. Good lighting should not be a random accident or an afterthought. Scientific photographs cannot embellish, amplify, or distort characteristics of subjects. The lighting that is created must reveal the characteristics of the subject and NOT imply a bias or lead to a false perception about the subject that compromises truth and scientific veracity. Science pictures must be about science facts and not science fiction.

Sometimes creating factual pictures can be more challenging than the process would be presumed to be. How lighting is used can be one element for changing the visual data revealed from a sample. Photography is an interpretive process. Just like a lens forms and shapes an image and an aperture influences the range of focus in a picture, lighting defines and reveals facts about an object. This outcome is based on decisions and knowledge used by the scientist photographer. Lighting can change the emphasis and make common subjects look dramatic. It can distort relationships of elements contained within the frame or make the subject appear normal as a viewer might expect it to be. Where the brightest light is shined or how the other qualities of the lighting are used to create emphasis is similar to how adjectives are used in writing. The elements and their relevant aspects can be diminished or embellished simply by where and how a light is shined onto a subject. Producing effective lighting is a process that starts with an analysis of the sample and what and why it needs to be revealed and recorded.

The subject will always play a fundamental role in the development of effective lighting. A subject can be opaque or shiny like a dissection scissors that broke during a procedure. Subjects can be translucent or opaque. They can be relatively flat or very 3-D. A sample’s contrast or surface characteristics will dictate what is needed and where to place a light. A subject's dimensionality or shine will influence how diffuse or broad the light source should be to create a certain outcome. There are a myriad of variables to consider. Rarely will one lighting method work for all things in the laboratory.

Light sources come in a variety of sizes, shapes, and types. Continuous or short duration discharge is but one of many features to consider when selecting lighting equipment for a particular subject. Each feature of a light will play a role in how the creation of lighting and its related outcomes will work to reveal information about the subject.

Fundamental methods for lighting and modifying lights used for artificial lighting will be shared as an overview. For the more interested reader, I suggest you seek out other more detailed books written on artificial light and studio photography techniques. For all artificial light photography, the concept of a main light and a fill light is fundamental. Because people live in a world with only one light—the sun—there is a subliminal expectation by a viewer to see only one shadow. The main light will make a shadow and the fill light will make the shadow more or less gray. A direct and small light will make a very black and sharply defined shadow, and a diffuse and large light will make a less defined and gray shadow.

Fiber optic lights are unique lights and versatile for the laboratory environment. An important part of the fiber optic light will be its light guide. Fiber optic lights deliver light to a very small and precise location using a pipe or light guide. This is accomplished through the use of fiber optics. Light guides or pipes are composed of hundreds—if not thousands—of microscopic glass fibers that begin at one end of the light guide where the light enters the fibers and then terminates where the light leaves the fibers at the other end of the guide. The fibers, on average, are slightly larger than a human hair. They are fairly robust but remain vulnerable to breakage when used without concern for their care. These fibers cannot be bent into a 90° angle or dropped on hard concrete floors. Dropping a light guide will certainly break fibers. As fibers become damaged, their ability to transmit light will become diminished, and the brightness of the light will go down.

Fiber optic lights are ideal light sources for laboratory photography. There are other lights that can work but fiber optic has the best cost-benefit balance. A fiber optic light is comprised of a light housing or lamp box that is compact and contains a very bright light. They can be LED or tungsten halogen. The light is directed by fibers into a bundle of light that forms a small circle of light. The brightness will be adjustable and there may be a fuse on the unit as well. These lights can be outfitted with a variety of light guides. Fiber optic lights are sold in a variety of models ranging from inexpensive to very expensive. The cost for a unit will be influenced by how robust it is and whether the brightness can be reduced by voltage or through the use of a graduated neutral density filter. LED light models will use pre-stepped brightness range settings. More expensive units will also come equipped with fans that are dampened for vibration and may have the ability to operate brighter bulbs. The heat and air currents from a lamp and its housing can affect delicate biological subjects by causing them to move or dehydrate. Illuminators with robust fans will not be ideal for photography because of the heightened vibration they create that can affect image sharpness.

It is quite simple to check a light guide for damage by removing it first from the lamp housing. By pointing one end of the guide toward a light, and using a finger as a shutter, it is possible peer into the guide to determine the percent of fibers that are not transmitting light. Put a finger over the end of the guide near to the light and open and close the finger over the end of the guide when pointing it at a light. You will be able to see what fibers are broken. Broken fibers will appear as black dots within the guide and fibers that are transmitting will be visible as white dots.

Fiber optic light guides come in a variety of types and sizes. They are unique to specific lamp housings and the types and size of the coupling port. Common light guide styles might include a single or bifurcated rigid gooseneck. The light guides can be encased in rigid coaxial cable or flexible casing, which allows the light to be positioned and remain in that location. Rigid guides that allow positioning can be very practical. The following is a short list of other types of light guides. Each light guide has typically been optimized for a specific type of subject or how the light might be used:

- Straight and single fiber optic light guides
- Dual-branch bifurcated fiber optic light guide
- Multiple gooseneck light guides
- Quartz light guides
- Ring lights guides
- Line lights guides
- Back lights guides

The rigid bifurcated gooseneck model is the most useful across many diverse applications. A ring light and line light can be useful for lighting when the working distances are small and access to a sample can be a challenge. Ring lights make omnidirectional lighting that is low contrast. Ring lights are useful for non-shiny objectives where color and textural surface information is the subject. When used with reflective objects, a circular reflection of the light will be evident in the photograph. Line lights are great for showing texture when placed at an acute angle to the subject's surface. This light will not produce as much contrast as a direct or point light from a gooseneck light guide.

22.30 Making Good Light

Good light is the product of knowledge, skills, a good sample, and using the right light source and/or modifier. Depending on the subject, effective lighting can be pretty easy to achieve or really challenging. It is easy to make things complicated: the lighting should work without becoming the subject of the photograph. It is useful to use only one light. In addition to the brightness and color temperature, the physical size of the light guide is an important characteristic for artificial light photography. Picking and purchasing the right light guide is an important decision. It is a costly accessory and acquiring a few may be cost prohibitive. They can be as small as 4 mm in diameter or as large as 15 mm. The smaller the light source, the more light contrast and directionality will be possible. The larger the light source, the less contrast it will make. A light should be proportionally sized to an object's size. As a rule of thumb, small subjects benefit from using small lights and larger subjects may benefit from using larger lights.

The term "quality of light" describes how the light achieves, or does not achieve, effective lighting on a particular subject. Quality refers to the characteristics of the light such as direct or diffused illumination. Direct light is very harsh and creates hard shadows. Harsh light can come from the sun, the raw light that leaves the light guide, a small on-camera flash or even a candle. The size of the light has a direct relationship to the harshness of the light. Quality of light is one measure of the type of the light, and the other is the direction of the light.

When making lighting decisions, it is important to consider what you are trying to show and how the light interacts with the sample or its surface: its color, texture, shape, topography, surface information, or any other relevant characteristic of the sample that need to be made more visible. Lighting can come from above the sample is called reflected light; light coming from below a translucent or transparent sample is called transmitted light. Some samples will require both transmitted and reflected light to show surface and internal structure characteristics.

22.31 White and Neutral Backgrounds

Subjects can sometimes be transparent and benefit from using transmitted light. Producing uniform transmitted light when not using a light microscope is not overly complicated, but there are challenges to create a uniformity of brightness across the field of view. A light box will be the most effective solution for making even lighting, but shining lights from the light guides onto a white piece of paper can also work. Using ping-

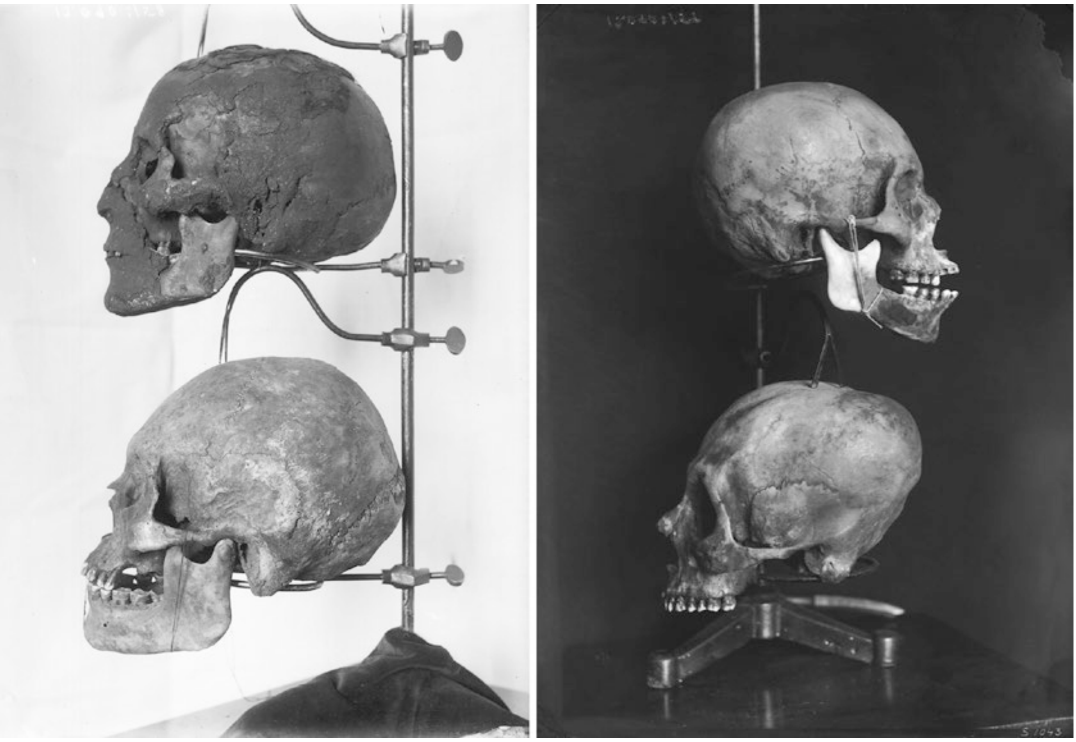

Fig. 22.14 Early examples of laboratory photography made by Swedish physician and medical photographer Carl Curman, Karolinska Institutet, circa 1865 show how two different backgrounds can produce different results. (Image courtesy: Routledge/Hagströmerbiblioteket, The Hagströmer Medico-Historical Library. Karolinska Institutet)

pong balls on the ends of the light guides can be helpful to spread light out more evenly. Creating uniformity across the entire field of view of the lens is very important. If the light is not uniform, false data can be created in the image as well as creating other image artifacts. While the background is not the subject in science pictures, it will play a role in the image chances of success. A well-managed background is a fundamental expectation in science pictures. Irregular tones and textures will compete with the sample for viewer's attention (Fig. 22.14).

A laptop screen can be used as a white background to create uniform backlighting since it is neutral and uniform. To do this, it will be perfect to create an image file of 255 RGB with light in white tones and a file of 3000 × 2000 pixels. This file is then displayed as a white image on the screen. When displayed, suppress the appearance of all docks and sidebar menus. You can then place a subject in front of the white screen using some sort of an improvised holder. The computer screen works best for samples that can be suspended vertically in front of it. It is possible to redirect the light using a mirror or by laying the laptop screen on its side. Care must be taken when working around liquids for obvious reasons. An iPad® can make backlighting which is easier than a laptop. The size of the screen will dictate how large of an object can be transilluminated. Using a petri dish filled with milk can also be a terrific white background. When lit from below, whole milk will act like a diffusion filter and is surprisingly neutral. Depending on the sample, the milk will also remove the infrared or heat from the light.

There is an important ratio required for backlighting when some front light is also needed. The amount of light shining onto the sample when compared to the amount of light shining onto the background should have a 1.5 *f*-stops difference. If the background is less than this amount, it will photograph as a gray, and if the background is brighter than, this amount it will be too bright causing the background exposure to bleed into the subject located in front of it.

22.32 Making Contrast

Contrast is an important element in a photograph. Increased contrast will make pictures look sharper even though they may not be. Creating more contrast can be accomplished in several ways. One of the quickest ways to increase contrast is to move the light further from the subject. While the brightness goes down, the size of the light will become proportionately smaller relative to the object's size. As a smaller light, it will create more contrast on the subject. The location of the light relative to the object can also modify the contrast the light produces. Having a light proportionally sized that is brought closer to the subject will make less contrast when located at a 90° angle to the surface of the subject. This technique might be called *edge or texture lighting*. If light is raked across the surface of an object it makes more surface contrast than if the light comes from the same axis as the point of view of the camera. A small light used from an acute angle will make strong raking light and produce shadows that will be very black. The reason to make this lighting would be to show surface structures and textures.

The brightness ratio of brightest elements in a photograph or highlights when compared to the darkest shadows of the scene is called the *luminance ratio*. When light is added to the shadow side of the scene, this light is called *fill light*. Adding fill light will lower the brightness ratio and contrast. The brightest light used in a photograph is called the *main light*. It is the dominant light for the photograph, and any other lights would be considered fill lights. The main and fill lights are described as having a ratio. A fill light is most frequently located at or near to the camera but not always. A lighting ratio of 1:2 means the brightest part of the picture will be 1 *f*/stop brighter than the darkest region. A ratio of 1:3 will make the brightest part of the scene 2 stops brighter and so on. The higher the lighting ratio, the higher the contrast will be visible in the image. A lighting ratio of 1:1 describes lighting with an equal brightness across the entire field of view. Digital cameras can typically record a 6+ *f*-stop range from the darkest tones to the brightest of tones. Once the brightness range exceeds this *f*-stop range, detail will not be recorded either in the darkest or brightest regions depending on how the exposure is adjusted. HDR or high dynamic range methods are required for creating a file with detail in both the brightest and darkest parts of the picture.

In scenes produced from fiber-optic lights, fill light can be added by using another light source of similar color temperature or simply by using a small white card or a small piece of aluminum foil to reflect light back into the scene. By varying the angle of the reflector card to the camera and the distance to the subject, the amount of brightness reflected into the shadow can be adjusted. Fill cards for small objects can be held in place using many strategies including modeling clay, or a *third arm*—a soldering tool accessory-, a lab stand with black tape, and even a piece of an aluminum soda can. The physical space under the camera often will typically be small. Creating the correct lighting ratio is a very important feature in a photograph and needs to be carefully managed in a small space. Adding fill is not an overly difficult adjustment to make. It is easy to add contrast to a picture in the captured file during software image post-processing. This being the case, it is best to create a relatively low contrast lighting ratio, which is sample dependent. Subjects that are already high contrast will benefit by photographing them using flat or low contrast light, and subjects that are low contrast will benefit from using lighting that has more contrast.

22.33 Reducing Contrast

To reduce the contrast, the light's surface must be made larger or it needs to be moved closer to the subject. A source of light contains both the bulb and sometimes a lamp-housing reflector. These items together affect the size of the light and subsequently softness or harshness of the light. Some lights may also use a convex-like mirror behind the lamp making the light larger. Moving the light closer to a subject can make the light larger proportionally to the sample. This method will have limitations to its effectiveness should be explored as a possible first attempt solution. Moving the light closer to a subject will increase the light's brightness and an associated exposure correction will be required. A better approach is to broaden the light by shining the light through a piece of diffusion material such as tissue paper or by shining the light directly onto a semi-reflective surface such as piece of white cardboard of appropriate size located near to the sample. The cardboard will reflect the light back onto the subject. Making the light source larger will play a big role in managing the light's contrast. Shining low contrast light with a low lighting angle (to the subject's surface) can be very effective in revealing a sample's characteristics and maintaining details in both the highlight and shadow regions of the scene.

It is easy to enlarge the surface of a fiber optic light guide by using 3M Magic® tape, or milky plastic bottles originally used for packaging products such as milk or ammonia (in the USA). It is also possible to use a ping-pong ball as a light diffuser by poking a small hole into the ball where the Logo has been printed. Keep the hole smaller than the diameter of the light guide. Once the hole has been established, the ball can be slid over the end of the light guide. When considering an object's size, this approach can produce excellent and well-managed contrast and uniformity of the light for many subjects. Highlights or bright reflections can be easily managed. This method is practical for semi-reflective metal objects such as coin, circuits, and many other things. A light's contrast when using this method will be affected by the subject's size, surface characteristics, the sample's texture, and the placement of the light. Similar to any other lighting methods, the light to subject distance will play a role as well in the image contrast.

A simple way to partially diffuse the light is to put 3M Magic® Tape loops over the ends of the light guides. The loops should use a generous amount of tape to make the loop. It needs to stand up and maintain a space from the end of the guide. The idea is to create some space between the tape and the end of the light guide to broaden the light. The tape will diffuse the light and hopefully make it behave as though it is larger than the actual end of the light guide. Using magic tape will not be as effective as ping-pong balls in making diffuse light, but it will work well for objects that are not too shiny or mirror-like. It can be helpful to use two or three thicknesses of tape stacked on top of each other to increase the materials ability to diffuse the light (Fig. 22.15).

Shining light through a milk plastic bottle is the most effective approach used to make a broad and diffused light. There are a few commercial products that can be purchased, but homemade light modifiers work quite well and come in a variety of sizes. It is best to cut the bottom and top of the bottle off leaving only the cylinder of the vessel as light tent. The height of the tube will be determined by the focal length of the lens. Once positioned around the subject, the light guide or guides can then be positioned at short distances away from the diffusion cylinder. This type of lighting behaves much like a light tent and subjects will be surrounded and bathed in diffuse and 360° light. It is possible to locate ping-pong balls over the ends of the light guides to further diffuse before the light enters the plastic creating the maximum effect.

22.34 Axial Lighting

Axial lighting is a unique type of light that creates illumination that appears as though the light came from the camera's lens itself or on axis with the camera. To achieve axial illumination, a beam splitter is located at a 45° angle to the lens between the lens and the subject. When using axial lighting, 50% of the light that is shined onto the beam splitter will be reflected down to the subject and 50% will be transmitted through the glass and away from the subject. Axial illumination

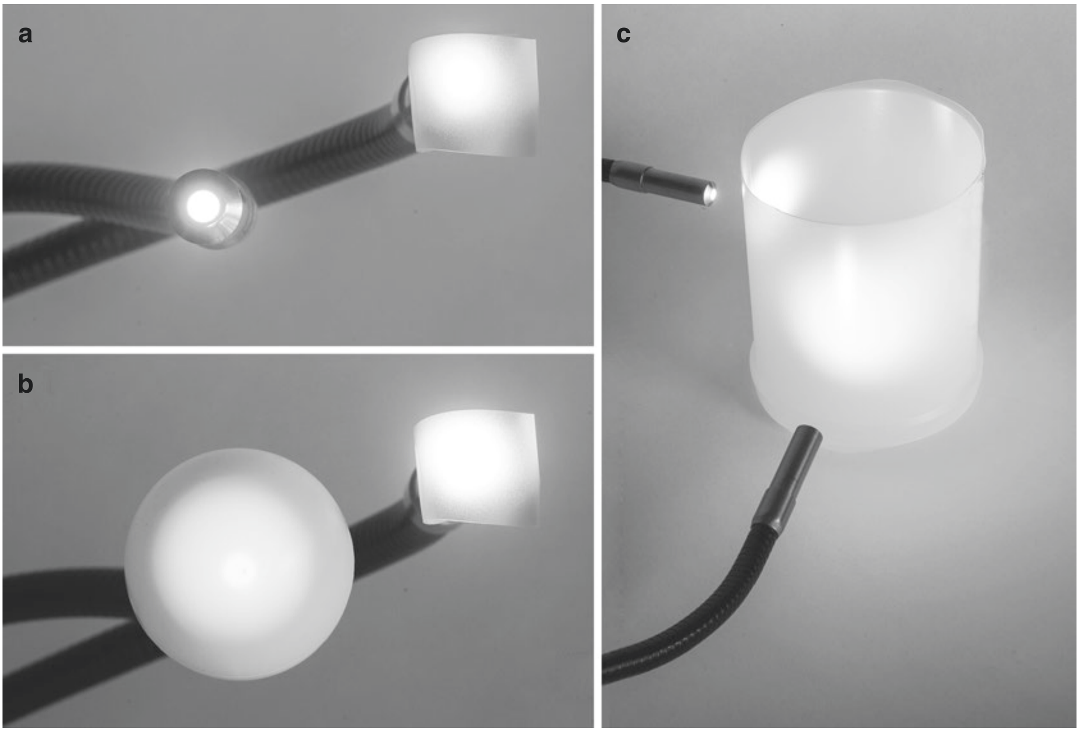

Fig. 22.15 Light guides are small lights and create high contrast or specular light. Sometimes less contrast is needed and a flat lighting is needed. It is relatively easy to create diffused light using a cellophane magic tape (**a**), ping-pong balls (**b**), or recycled plastic bottles (**c**) that are used for liquid products such a windshield washer solution or milk. In each case, making the light larger reduces the lights' contrast. (Image courtesy of Routledge/Michael Peres)

produces lighting that is nearly shadowless and exhibits a high degree of contrast on the surface of the subject. It is very useful for shiny objects such as coins and circuits. It reveals surface texture and structure without the creation of directional shadows that obscure detail (Fig. 22.16).

Axial lighting can be tricky to set up but once established will be an excellent strategy when used on the proper subject. Pre-cleaned microscope slides or cover slips depending on the size of the subject can serve as beam splitters. A point and small light source such as a small fiber optic light guide would be required. The glass beam splitter should be located above the sample and positioned at a 45° angle to the surface of the subject. The camera lens is located directly above the beam splitter. There are no photographic challenges when using axial lighting but there are a few things to keep in mind about lens and aperture settings. Because of the laws of physics, the light that strikes the sample travels in the same pathway that the image does. For this reason, it is imperative to photograph using a nearly wide-open aperture. When an aperture is closed to a smaller diameter it results in more DOF. If the DOF of the system is large, the "light" reflecting off the beam splitter will become defined and this will create flare or non-image forming light in the system. The diameter of the lighting coverage is also affected negatively. The circle of illumination will get smaller as the aperture is closed.

Never use autofocus for technical photographic applications, especially in axial lighting setups. It is also very important to ensure the beam splitter's alignment achieves the same height across the sample from left to right. It is practical to use modeling clay or a third arm soldering tool to position the beam splitter. It can also be helpful to locate a small piece of black velvet on the side opposite of the light itself. The surface of the beam splitter that is away from the light may reflect the ceiling or others things the back into the lens. It is also better to work with the room lights dimmed or off.

Fig. 22.16 Axial and diffused lighting can create very different results. In this composite, the middle image is or a US quarter illuminated using axial lighting. The bottom image was created using diffused lighting. More surface characteristics are revealed in the axial and higher contrast lighting. The image's structure exhibits more crispness and the image appears to have some relief when compared to the flatter and more diffused non-directional lighting used for the bottom image. (Images courtesy of Routledge/Torey Miller)

22.35 Laboratory Glassware

Glass is an interesting subject to photograph because it has 360° of reflective surfaces. It can be colored or neutral. It can also be full of liquids such as might be the case of a test tube or other flask for example. Because of the importance of controlling specular reflections, it can be very useful to significantly broaden a light source or to back light from behind the subject. Broadening a light source can be accomplished using a white cardboard. This is an excellent strategy to start; however, it will create a large and soft white reflection on the surface of the glassware. A better way to light glass is using white line and dark line lighting. When making dark line lighting, first place a white or light gray background behind the subject. It does not need to be huge but simply should fill the camera's viewfinder. Place the glassware on a sheet of glass that is elevated above the table. Allowing light to enter the glassware from the bottom will produce better lighting. Once composed and focused, shine a small spot of light directly behind the subject. This will make the subject appear backlit and display dark edges. It is important to the keep the raw light from the source from striking the glassware. Place the light somewhere in the front of the object, and then use cardboard to block any direct light from striking the glassware.

Darkfield lighting is useful for revealing defects and inclusions and it will definition the edges of a semi-transparent material. To produce this type of lighting, a piece of black material should be located behind the subject. This black material needs sufficient to be large enough to cover the field of view of the camera. Two lights should be located outside the field of view and shine through the subject from behind using an oblique angle of view to the camera lens. It is also helpful to locate pieces of black cardboard or other black materials to act as a curtain or baffle to the lights. The objective is to create a slit of light that comes from behind the glass subject. Light coming from this direction will become trapped within the vessel and cause the edges of the glass to glow. When possible, it is important to clean the glassware carefully using lint-free materials. It might also be advisable to use a dusting brush as a final treatment prior to depressing the shutter. Fingerprints and other particulate materials can quickly become the focal point of a darkfield lit photograph if prominent in the composition and made visible by this type of lighting (Fig. 22.17).

Fig. 22.17 Laboratory glassware can be a challenge to light effectively. Managing stray reflections is one of the primary challenges. The image on the left was made using dark line glassware lighting and the image in the middle was made using white line lighting. It is very similar to how darkfield lighting used in microscopy is created. (Image courtesy of Routledge/Michael Peres)

22.36 Metal and Tent Lighting

Shiny objects like glassware can be difficult to light. Similar to glass, highly polished metal or mirrors have an entirely reflective surfaces that will reflect back anything that is in front of it. Lights, cameras, and even the photographer can be reflected back to the camera. Depending on the size or prominence of the reflections, they can be a terrible distraction.

Better lighting can be achieved by making a very broad light, which also will reflect itself in the subject but will be more pleasing and less random across the highly reflective surface. A sometimes better approach is to light the mirror like surface using what is called *a tent*. A tent is used for surrounding a subject with a uniform white surface. White cardboard, for example, or something such as a white shower curtain might work very well. The subject's size will influence how large of a tent is needed. There are commercial products for jewelry photography. A light or lights can be shined through or the inside of the tent, which will be reflected in the highly polished and reflective surfaces of the subject. On occasion, it can be effective to locate pieces of black paper or other appropriate materials to create desired reflections in strategic places. This modification may be useful to break up the tent's monotone reflection.

22.37 Immersion

Subjects that are wet can often benefit by being photographed under water. The goal of keeping a sample wet is to manage surface specular reflections. When a light is shined onto a wet object, the various topographical structures of the subject will produce many reflections. These reflections will be random and may possibly obscure important details about the sample, but they also share the subject is wet. It is possible to eliminate all reflections by placing a sample underwater in an appropriate liquid. This approach will eliminate reflections and needs only one light. Using distilled water or water that has been de-oxygenated by evaporation over time is the best for obtaining this result. It may be necessary to hold the sample below the surface of the liquid through the use of some type of a weight. Many objects will float. Using one small light, the surface of the subject can be illuminated without the presence of any specular highlights to obscure surface details. Immersion management and lighting will create low contrast lighting. It might be useful to add

Fig. 22.18 A crab apple was cut longitudinally and would be categorized as a wet object. The image on the left reveals countless specular reflections on the fruit's surface. "Speculars" are the by-product of a wet surface when photographed using a small light source. In the image on the right, the crab apple was submerged in a water bath and the specular reflections disappear when using a water bath. Only one reflection is produced and is on the surface of the water. It can be easily cropped out or the light located in a better spot for a particular situation. (Image courtesy of Routledge/Michael Peres)

contrast to the picture during the image processing because the lighting can be flat and low contrast (Fig. 22.18).

22.38 Light Microscopy

22.38.1 Introduction

Making pictures using a light microscope can be challenging but has never been easier. There are numerous problems that require management and needed to be solved to create effective results. Some of these challenges include:

- Working with nearly invisible 3D subjects
- Working with very small working distances
- Managing physical and optical behaviors that affect light traveling in and out of glass or other materials that directly affects image formation
- Operating lenses that have a small and finite range of focus
- Managing the presence of optical aberrations
- Managing the presence of dirt/artifacts in an imaging system

Forming highly resolved images of infinitely small objects requires a working knowledge of applied physics. It also requires careful attention to the influences of the sample itself in the characteristics of the formed image. This part of the chapter will focus on sharing core principles and other fundamental approaches needed to successfully form and capture images produced by a compound light microscope. There is not enough space, nor need, to discuss all of the complex laws of physics that play a role in image formation.

The interest to see more than the human eye can resolve has inspired discovery and innovation in science, optics, and photography for centuries. Curiosity when coupled with the invention of new tools has accelerated the ways physician/photographers have been making images. The release of new products does not show any signs of slowing and as such, light microscopy will continue to benefit from new and better products from innovations in optics, imaging, and computing.

In the mid 1980s, there was a bit of a renaissance for light microscopy as a consequence of the release of several new technologies. Computing had improved enough that it could be coupled to newly re-designed optical research grade microscopes that were being outfitted at the time with digital cameras and software. As a consequence, light microscopy and imaging began an expansion of new discovery and probing the boundaries of what was possible. This expansion has not slowed down in more than 20 years and thanks to technology, the future will probably be filled with new discoveries both in science and imaging.

22.38.2 Fundamentals of Magnified Images

Users of a microscope rely upon direct observation whether traditionally using a microscope's eyepieces or when viewing the image on a monitor. Microscopists are frequently reminded about how the human vision system functions and how it influences the process of observing a magnified image that is sometimes very dim or poorly formed. A working knowledge about human vision and anticipating how to maximize a system can be an important advantage when looking at nearly invisible subjects and determining what is real and what is perceptual or even illusional.

A compound microscope is a complex optical instrument designed to magnify very small objects. It forms images that can delineate fine structures contained within a larger sample. The ability to delineate structures is called *resolution* (optical). To see structures within an image, a microscope must create the three outcomes: (1) a microscope must be able to magnify; (2) it must be able to discriminate fine details within the sample (resolution); and (3) it must be able to create/maintain sample contrast necessary to delineate structures within the sample. These three outcomes assist in making things visible to the eye, camera, or other imaging devices.

A compound microscope produces an *aerial image*. An aerial image is formed by a positive lens and is located in space. Aerial images can be focused onto a screen (or in the eye), placed in the optical path and at the location where the image is focused. The microscope's aerial image is relayed to the retina by the operator's cornea/lens, or to the camera's sensor by a lens called an eyepiece. It is important to keep in mind that the human lens and the eye's refractive properties are influenced by age and will behave as an optical element of the microscope. Younger eyes are more elastic and can see more easily at shorter distances. As the human eye ages, it becomes less elastic and near vision becomes lessened. Because images formed by microscopes are aerial and their interpretation varied by perception, they can be challenging. Sometimes, aerial images create illusions or the perception that something was seen much in the way stars twinkle at night, even though they were not seen at all.

Microscopes form images that are larger than the subject. The following pages will share principles used in brightfield or now more commonly referred to as widefield microscopy. Brightfield method is the most fundamental of all the microscopy techniques and consists of illuminating the sample from below and observing from above. The name comes from its typical appearance: a dark sample on a bright background. White light is shined through the sample in brightfield method.

22.38.3 Optical Magnification

A compound microscope uses two lenses to create magnification. The initial stage of magnification is produced by the primary lens or objective. Once formed, the primary image is further magnified by a second lens, the eyepiece, which relays the now magnified image to the eye or a camera. The first lens produces a real image, while the second lens may produce either a real or virtual image. A real image is an image that can be focused onto a screen and a virtual image is one that can be seen, but cannot be focused without additional lenses onto a screen. Together they form a real and inverted image that is larger than the subject. For example, if a 10× objective were used with a 5× eyepiece, the combined image will be magnified 50 times or ×50. When referring to the lens magnification, the number typically goes before the ×, e.g., 10×, but when referring to the total image magnification, the "×" precedes the number, e.g., ×100. ×50 is the proper way to indicate image magnification, and 50× is the proper way to indicate an objective.

Estimated magnifications of a system can be determined by multiplying the magnification of the objective and eyepiece. This calculation provides an approximate magnification of the images that is seen; however, photographing a stage micrometer—a microscope ruler—is required to determine the exact magnification for a microscope's imaging system. Stage micrometers come in different calibrations, and a 1-mm scale often is subdivided into 1000 μm. An imaging system (where the camera system is located) will often have a different magnifications than the images that are seen by the user in the eyepieces. This is due to variances in the image projection distance between the photo/imaging eyepieces and magnification of the two eyepieces. Many research grade microscopes will include a software that can also create a measurement system for magnified images once calibrated. Calibration is accomplished by using a stage micrometer to configure the imaging software's scale. Imaging software can count pixels but cannot measure itself without being calibrated to pixel distance. It is also possible to calculate the system's magnification if the image projection distance from the eyepoint to the sensor can be measured.

$$\text{System Magnification} = \text{Eyepiece }(\text{mag}) \times \text{Objective }(\text{mag}) \times \text{Projection distance} / 250\ \text{mm}$$

This equation describes how the magnification is determined by observing an object of known size, and then measuring the size of its image when projected 250 mm from the exit pupil of the instrument or in the case of the microscope, 250 mm from the exit pupil of the eyepiece. In some literature the eyepoint is called a *Ramsden disk*.

The microscope's objective produces the primary image. The quality of this image is influenced by the objective's characteristics and focuses its image into the microscope's body tube. A body tube is the long tube that holds the eyepiece and connects them to the objectives. The image is actually formed at the intermediate image plane, a location that is situated within the body tube. Another important optical location visible within the body tube is the exit pupil of the objective. The exit pupil can be observed in the microscope's body tube when an eyepiece has been removed from the instrument. The body tube is the tube-like structure that is it located between the place where the objectives are mounted onto the nosepiece (turret) and where the eyepieces are located on the microscope. The primary image comes to focus at the intermediate image plane in the body tube. The intermediate image is also located at the front focal point of the secondary magnifier, the eyepiece. Being aware of these locations can be useful when having troubles making image visibilty. More than 20 years ago, microscopes were built to have specific tube lengths, e.g., 160 mm. Today contemporary instruments are designed to use infinity ∞ corrected objectives. Exit pupil locations and intermediate image planes are useful for alignment of phase contrast optics and play a somewhat lesser role for other applications.

Once the primary image has been formed and relayed through the eyepiece, the image will exit this secondary magnifying lens at a location called the *eyepoint*. The eyepoint can be observed by holding a piece of paper near to the lens and will be visible as a tiny dot of focused light situated very near to the eyepiece itself. If the small piece of paper is held approximately 1 cm from this lens, a very bright small dot will be visible on the paper. Moving the paper closer or further from the eyepiece will allow exact determination of its location. The eyepoint can be a useful location for imaging. A smartphone's lens, for example, can be placed at the eyepoint, which will allow the smartphone to make photographs of the image from the microscope. When photographing using a fixed lens camera such as compact digital camera, the front of the camera lens must also be placed at this location as well. In today's era of compact digital cameras, it is a relatively simple to make "adequate" photomicrographs using this method. A fixed lens camera can also be used this way. A camera stand or tripod will be required for best results. With surprisingly

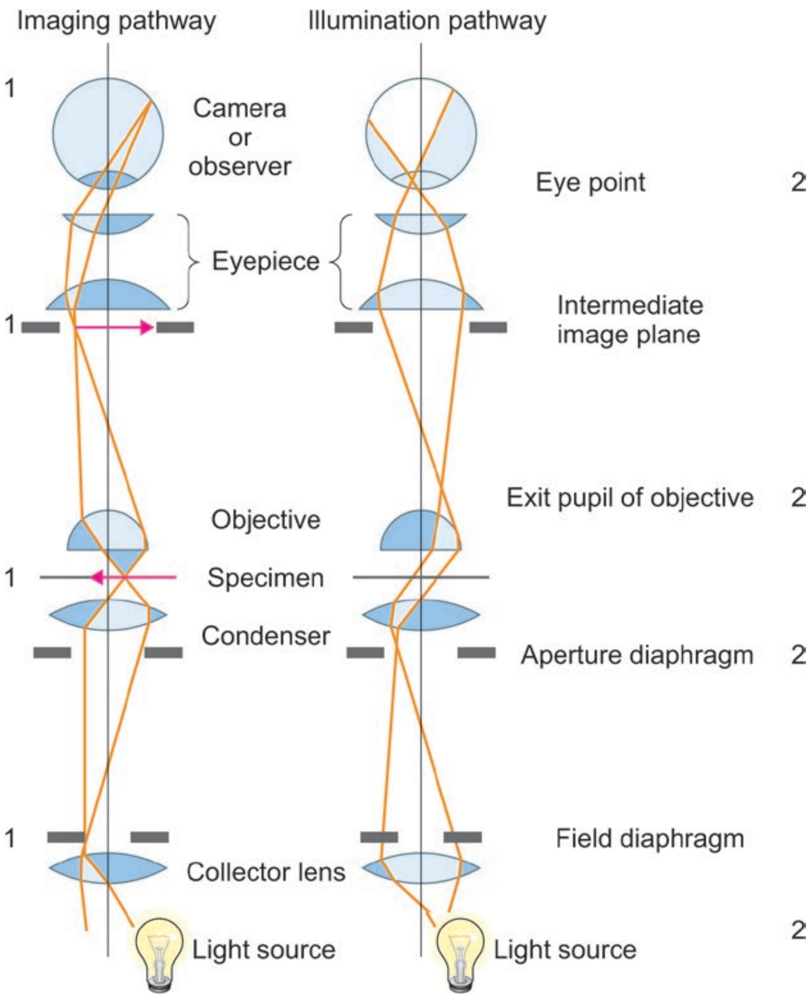

Fig. 22.19 This illustration reveals the illumination and imaging pathways used when working with a brightfield compound microscope. (Image courtesy of Routledge/ Michael Peres)

improved sensor sizes, quite good photomicrographs can be produced with care and patience (Figs. 22.19 and 22.20).

22.38.4 Optical Elements in a Light Microscope

22.38.4.1 Eyepieces

Observation of the image occurs when looking into the microscope's viewing eyepieces sometimes called *oculars* or on a monitor. There are different eyepiece lenses used for imaging systems besides than for viewing. Typically, the imaging system's field of view will be less than the viewing system's. Although a viewer may see two images in the binoculars and some may consider a microscope's image to be stereo, it is not. The primary image is formed from a single objective having a single point of view. A microscope with only one eyepiece is called as a monocular microscope and a microscope with two eyepieces is called a binocular microscope. Two eyepieces will be used on binocular microscopes and a microscope with three eyepieces is referred to as a trinocular microscope, which has two viewing ports plus one imaging port and is often called a photomicroscope. Trinocular microscopes are typically designed for imaging and there may be other imaging ports added as needed.

One or both viewing oculars will come with adjustable diopter correction(s) for each eye. There is a neutral position (0) as well as + and – settings. Each eye will require a different diopter setting to

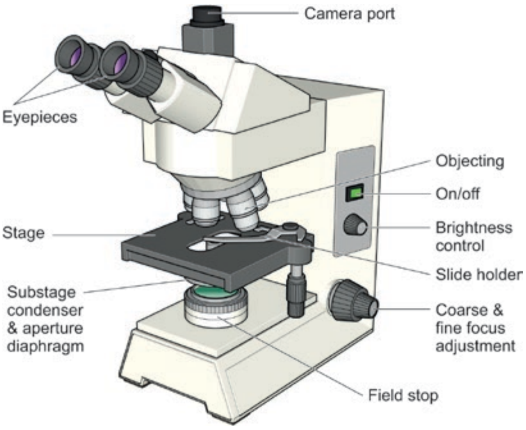

Fig. 22.20 This illustration shares the key parts of light microscope. Knowing where each of the controls are situated on microscope can enable an operator to improve imaging outcomes in much the same as drivers must know where all the controls for operating an automobile are located. This knowledge might be called "knobology." Never looking away from the sample during evaluation can allow very subtle differences in an image to be evaluated. This might include not blinking. (Image courtesy of Routledge/Michael Peres)

create the best focus for the unique vision for each eye. Users should be aware of which is their dominant eye when establishing the correct diopter setting. Not adjusting the eyepieces properly for each eye will lead to eyestrain and headaches. Both lead to the formation of inferior images.

There are two main types of traditional viewing eyepieces, Ramsden and Huygens. There have been improvements to their design over the years; however, they are basically the same as when they were invented and compromise the majority of basic eyepieces used today. Depending on design of the lenses and budget of the operator, Huygens negative lenses are most frequently used with most achromatic objectives and positive highly corrected eyepieces, Ramsden are used with the finest apochromatic objectives. A good strategy when considering what eyepieces, consult with a knowledgeable instrument salesman. The selection of the microscope's objectives will influence the choice of eyepieces, which leads to the optimization of the optical performance and improved imaging.

Proper viewing conditions are required to look at magnified and sometimes very dim and low contrast images. Gas lift chairs are recommended for extended shifts at a microscope and should be adjusted each time a different operator sits down. It is important for an instrument's eyepieces to be situated at the height of the viewer's eyes. The best practice when sitting at a microscope requires an operator to raise or lower the chair to locate the eyes at the height of the eyepieces. Viewing oculars should be located at eye level. This will minimize body strain such as stretching of the neck or simply having poor posture. Not managing these conditions including poorly adjusted eyepiece diopters can lead to headaches and ineffective results. Being in an uncomfortable position will produce inadequate work. The lights in the room where the microscope is located should also be lowered or turned off completely when necessary.

22.38.4.2 The Prism

All instruments use prisms or beam splitters to direct light into different optical pathways within a microscope. Once an image has been formed by the objective, it must be relayed to the viewing ports, to the imaging system, or to a video port. Once at the prism, the real image can either be directed to the viewing eyepieces or to the camera by changing the setting of the prism/mirror. This change of light pathway can be accomplished either manually or by automation in research-grade microscopes. When photographing, the prism will need to re-direct the light to the camera's imaging lens and away from one or both the viewing eyepieces. The prism is located within the head of the microscope and may be rotated using a plunger or other method used to redirect the light. Adjustments to the prism will cause the light to be re-directed either partially or completely. Frequently there will be a minor loss of brightness in the prism. Prisms can influence the light re-direction in various specific percentages. This could be 20% to the viewing eyepieces and 80% to the camera, 50–50%, or 0–100%, for example. If the instrument's prism is of low quality, or a first surface mirror, optical degradation can occur to the image as a consequence of poor optical glass and correction of the prism. Flare and dispersion might be introduced at this location. When using fluorescence technique, a 100% beam splitter is the ideal choice because a fluorescence image will exhibit a very low image brightness to start. It should be noted that one of the most common things photographed in a microscope is dirt. Dirt can find its way to the prism may be recorded in as dark spots on the image. Dirt will also image as a shadow or dark spot by casting a shadow on the sensor.

22.38.4.3 Photo or Imaging System Lenses

When using a trinocular microscope, there is a third tube that contains the eyepiece lens called the *photo or projection lens* (eyepiece). It is so named because it relays the magnified image to the camera system. The eyepiece features will be inscribed on the eyepiece barrel or can easily be found. Besides magnification, often it will list the degree of correction and share the field of view of the lens. The diameter of the eyepiece aperture (in mm) is called the field-of-view number, or *field number* (FN).

With the FN it is possible to calculate the diameter of the sample's imaging field. An eyepiece with a larger field of view is useful and practical and simplifies scanning a sample to locate an area of interest.

$$\text{Field size} = \text{Field number} \,/\, \text{Objective magnification}\left(\text{Om}\right)$$

All microscope eyepieces do the same thing: they magnify the primary image and relay it for viewing or for imaging. The photo eyepiece will usually be of higher optical quality than the viewing eyepieces and in many cases, the photo eyepiece may be of lower magnification than the viewing eyepieces. In fact, the photo/optical relay system may have a magnification that is adjustable when different specific magnifications are required. Some photomicroscopes may also have an additional optical zoom lens that is highly corrected and can be used to achieve just the right magnification based on object size. Many older imaging lenses will have the letter P or PHOTO inscribed on the lens. This information means that the lens has been specifically designed for picture making applications and has flat field correction. Photo relay lenses are made and manufactured to the highest degree of correction that manages the presence of aberrations. Since sensors are smaller than film, contemporary imaging eyepieces can be 5× or 7× while the viewing eyepieces on that same microscope are 10×.

22.38.4.4 Substage Condensers

Located beneath the stage of a biological microscope is a lens called the *substage condenser*. The substage condenser is primarily responsible for gathering the microscope's light and concentrate it into a cone of light that illuminates the specimen and creates and maintains image contrast and definition.

The substage tends to be the least understood optical element in a microscope. Often this lens is completely neglected or used incorrectly. Similar to objectives, substage condensers have numerical apertures (NA), which describe their resolution potentials as well as their degree of correction. The substage condenser contains a diaphragm called the *aperture diaphragm*. This diaphragm will affect the resolution potential of the objective. The condenser's NA should be at least equal to that of the objective for optimal performance. Substage condensers play an important role in creating and managing image visibility by improving the use of illumination.

There are several types of substage condensers used in a brightfield microscope; some are used for contrast producing techniques. The three common types of brightfield condensers are (1) an Abbe condenser, (2) a flip-top or swing-out condenser, and (3) an achro-aplanic condenser.

The Abbe condenser is named for Ernst Abbe. The Abbe condenser, like any other condenser, focuses light that will pass through the specimen prior to entering the objective. Condenser assemblies will have several controls to properly operate them. One control adjusts the distance of the condenser to the sample and the other is the aperture diaphragm. Adjusting the height of the condenser affects the diameter of the beam of light and the aperture diaphragm controls the brightness, contrast, resolution and DOF. Abbe condensers typically have an NA of 1.25 and are useful for all types of microscopy and all mag-

Fig. 22.21 Left to right an Abbe, a Swing-Out or sometime called flip-top, and an Acrhro-Aplanic condenser. Many contemporary microscopes can be outfitted with what is called a Universal condenser. Each of these substage condensers will produce different cones of illumination. Figs. 22.24 and 22.27 to see the angle of cones of illumination from these condensers. (Image courtesy of Routledge/ Michael Peres)

nifications. As a general-purpose condenser, they are quite inexpensive and are useful with 4× or 100× objectives. As a consequence of their average quality and degree of correction, images will be adequate as well. They are not fully corrected for aberrations and will have a comparatively high dispersion (Fig. 22.21).

Swing-out—or sometimes called flip-top—condensers are designed for use primarily with low magnification objectives such as a 2× or 4× objectives. They have numerical apertures that are in the range of 0.65–0.95 since they are used primarily in air. They are quite versatile and are adequately corrected. The degree of correction is typically on par with achromatic optics.

An achro-aplanatic condenser is the most highly corrected condenser and is corrected for spherical aberration and chromatic aberration. It is quite expensive and typically has an NA of 1.35. There is also an aplanic condenser with an NA of 1.4, which was excellent for use in B&W film applications many years ago.

22.38.4.5 Objective Lenses

The single most important optical element in a microscope is the objective. The objective lens produces the primary image and creates first stage of magnification in the microscope. The objective lens influences the image quality, contrast, and magnification as well as all other characteristics in the primary image such as depth of field. There are several inscriptions engraved on the barrel of the objective lens. These inscriptions share the lens' features. It can be very useful when using a microscope for the first time to review the objectives and become familiar what types are on the instrument. Objectives are complex and have a number of internal lenses that affect the image attributes that the less can produce (Fig. 22.22).

An important inscription visible on the objective's barrel will be PLAN. PLAN refers to the objective's correction for flat field. Traditionally a biological microscope is used to photograph subjects that are flat and thinly cut sections that are placed on glass slides. Since a subject will be situated very near to the front of the objective, small differences in working distances will be amplified by the optical elements in the system. Consequently, small differences in the sample distances and proximity to the front of the object can make focusing difficult across the entire field of view. The correction for this problem is called PLAN or a PLANO lens. If the lens is not corrected for this, curvature of the field will occur and be observed. A lens not corrected for flat field will demonstrate focus in the center or on the outside regions of the image but not in both regions at the same time. This outcome is called *curvature of the field* (Fig. 22.23).

Another inscription on the lens barrel will be the objective's *magnifying power*. The magnifying power will be indicated using a number and

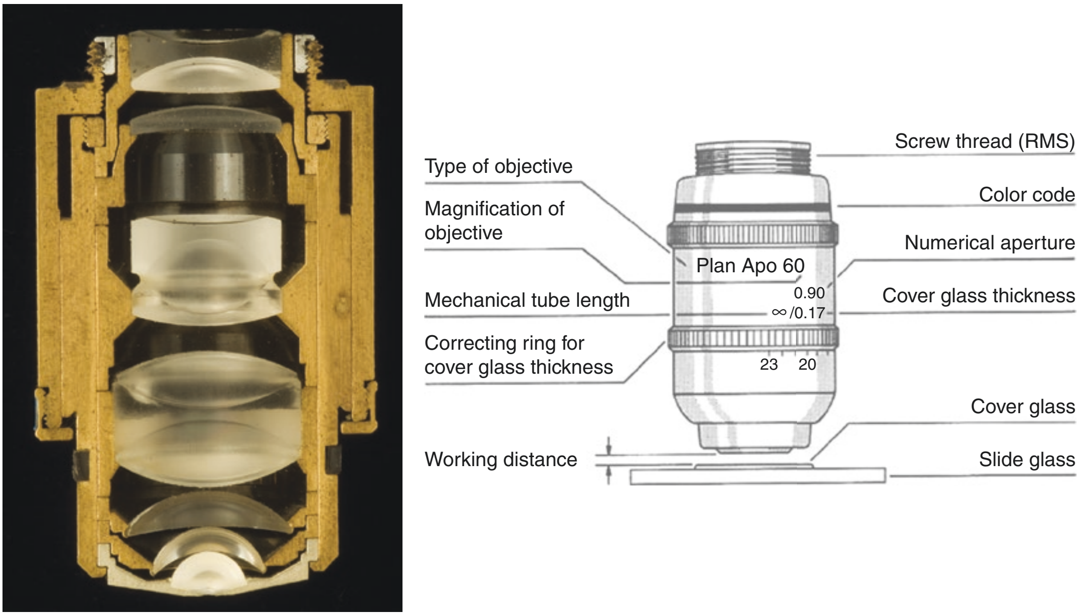

Fig. 22.22 This illustration shares the inside of a 100× APO Zeiss objective. On the right is a figure of the outside barrel of a 60× objective identifying what all the nomenclature describes. (Image courtesy of Routledge/Michael Peres)

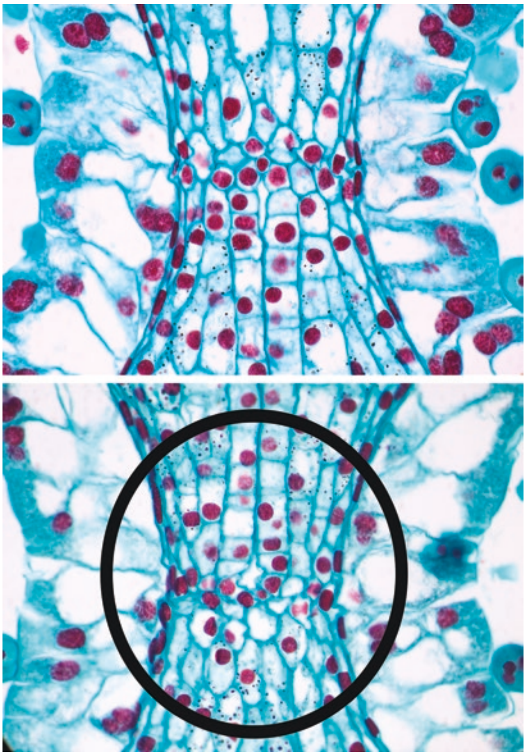

Fig. 22.23 This composite shows the effect of two different objective lenses. One corrected for flatfield and the other not. The top is an image produced from a PLAN objective and the one on the bottom, a non-PLAN objective. Notice the image area outside of the circle. It is not sharp. (Image courtesy of Routledge/Michael Peres)

maybe followed be ×, e.g., 10×. Each objective on the turret will have its own magnifying power. For those who have worked with photography, an objective lens has a focal length similar to a traditional photographic lenses used on DSLR cameras. The 10× objective has an equivalent focal length of a 16 mm lens. This can be calculated by dividing the objective's magnification into the mechanical tube length. Samples are typically placed at one focal length away from the front of the objective. A typical range of objective magnifications for a light microscopes might include a 2×, 4×, 10×, 20×, 40×, 60×, or 100×. These represent common magnifications but are not the only choices. There are hundreds of types of objectives designed for many unique applications.

22.38.4.6 Numerical Aperture

The quality of an objective lens is shared by its numerical aperture (NA). Often NA is shared as a decimal such as 0.45 or greater than 1.00 for higher magnification objectives. When the objective is used in air, the NA will be less than 1.00. When it is used with immersion oils, the NA will be greater than 1.00. The NA is a ratio of the light available for image formation measured against what is actually gathered up by the lens.

The higher the NA of the objective, the better the image definition or optical resolution. The higher the NA, the more the objective will cost. NA is also related to magnification. Typically lower magnification lenses will have lower numerical apertures and higher magnification objectives will have a higher NA. Higher NAs will create more optical resolution but produce less DOF.

22.38.4.7 Forming Images: Diffraction and Resolution

Before going into more detail about an objective's numerical aperture (NA), it is useful to understand how an objective forms an image. In microscopy, many aspects of image formation are described using diffraction theory. This idea was initially proposed by Ernst Abbe in the late 1880s while working with Carl Zeiss. *Refraction* is the bending of light as a consequence of a speed change to light when entering a new medium. This principle plays an important role in image formation. *Diffraction* plays an even more important role in image formation because it influences the objective's optical resolution. As the magnification of an image is increased, it becomes less defined. This can be caused by diffraction. When radiated energy encounters an opening (aperture), the interaction may cause several things to occur. The number of the openings in the tissue and the physical size of the apertures (opening) will determine how small or large the effect of diffraction may be.

An aperture in the pathway of traveling light might behave like an energy source itself. The edges of small openings cause some energy to be re-directed into new directions. The new directions will contain less energy but provide information about the structures with which it interacted. The size and direction of this behavior will be dependent on the diameter of the aperture. If the aperture is wide, most of the energy will travel through the aperture unaffected. In this situation, most of the peripheral energy will be bent slightly outward away from the original travel direction and having a minimal effect on an image. If the aperture is small, the bending of light away from the original travel direction will be greater. This becomes important because the sample itself is often a porous grating and will behave like many small and separate apertures. Objects that are porous are sometimes referred to as *diffraction gradients*. The smaller the fine structural details, the greater the light will be affected upon exiting the sample. The ability to delineate small details in a sample is described as *resolution*. The smaller the structural details, the more difficult it becomes for the objective to resolve these details. For a microscope objective to resolve detail, it must be able to collect all the radiated energy that interacts with the sample. This of course is impossible. The challenge arises when the energy leaves the sample after going through the aperture diaphragm in the microscope. As the energy interacts with various waves from across the sample, interference occurs. Interference can either lead to more visibility by creating contrast or produce a data loss and poor resolution. This outcome is a consequence of the objective being unable to gather all the now diffracted rays required to form resolved images.

22.38.4.8 More on Numerical Aperture

When characterizing a traditional photographic lens, a useful indicator to a user is the maximum aperture or *f*/stop of the lens. The *f*/stops can serve as indicators of light transmission for users. A lens' maximum aperture can be determined by dividing the focal length of the lens by the maximum clear diameter of that same lens. Microscope lenses are also described by their light-gathering potential. The factors which influence their performance would be the medium in which they are operated and the acceptance angle of the diffracted energy into the objective (Fig. 22.24).

The objective's NA can be mathematically calculated using the following equation. This information is provided to users for theoretical reasons and will rarely be calculated by a user. It is always important to be aware of how light travels in the microscope and how the aperture diaphragm allows to direct the light needed to form resolution of contrast.

$$\mathrm{NA} = n\,\mathrm{Sine}\,\mu$$

where n is the refractive index of the medium that the objective will be used in and Sine μ is the acceptance angle of that specific objective lens.

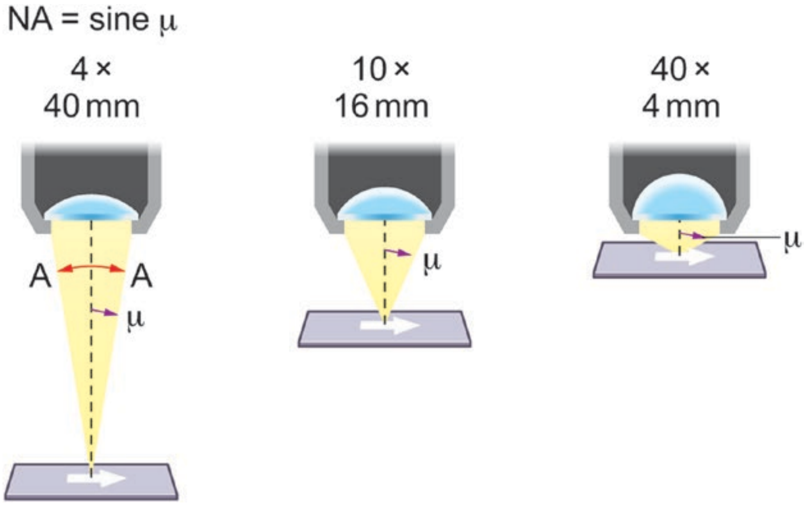

Fig. 22.24 In this figure, the relationships between working distance, magnification, and numerical aperture (NA) are shown. (Image courtesy of Routledge/ Michael Peres)

Air has a refractive index of 1.00, water 1.33, and immersion oil 1.53.

The NA of the objective is also influenced by the focal length of the objective. Shorter focal length lenses will have a shorter working distance and consequently a greater angle of acceptance creating more resolution. As the magnification goes up, so will the corresponding numerical apertures. The objective's NA will dictate the smallest of structural details that can be resolved. This smallest distance an objective lens can discriminate can be determined using the following formula:

$$D = \frac{\lambda}{\mathrm{NA}_{\mathrm{obj}} + \mathrm{NA}_{\mathrm{cond}}}$$

where D is minimum resolvable distance between two points and λ is the wavelength of light in the system. 550 nm is often used in this equation to represent white light.

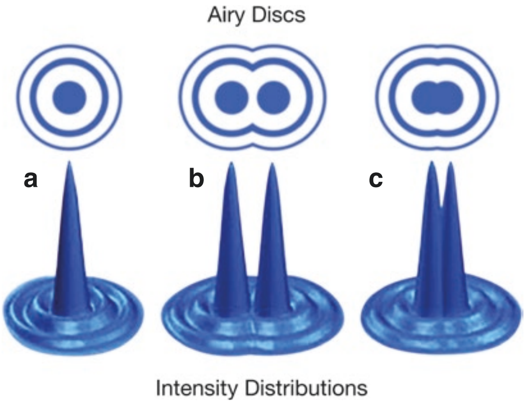

Fig. 22.25 An airy disk is a useful measure to predict how a location (point) will be modified when diffraction affects its sharpness. When two airy disks are adjacent to one another, sometimes diffraction will cause the two points to become one. Higher numerical apertures produce better resolution. (Image courtesy of Routledge/ Michael Peres)

22.38.4.9 Airy Disk

An instrument's optical performance can be predicted by considering the airy disk produced by a lens and the diffraction the system creates. An airy disk is defined as the best-focused spot of light that comes from a point of light formed by a perfect lens having a circular aperture. An airy disk will only be limited by the system's diffraction. The diffraction pattern resulting from a uniformly illuminated circular aperture is characterized as having a bright region in the center called the airy disk, and the disk is surrounded by concentric rings of diminishing brightness. The airy disk plays a central role in indicating a microscope's resolution. When the airy disk spreads, the outcome is called a *point spread function* and plays a significant role in image clarity and predicts whether independent points will remain delineated. Many confocal or other high-end research photomicroscopes will have controls to manage and influence the point spread function of an image (Fig. 22.25).

A sample's diffraction potential is a significant element of a system's performance when coupled with the objective's numerical aperture. Part of this theory can be understood when considering how light interacts with a diffraction grating. Light travels through the grating – an optical component with repeating structures – that splits and diffracts light into several beams travelling in different directions. What is not bent would be characterized as the light's zero order. To the outside of the zero order would be the first order of diffracted rays. The angle and departure of this deviation is a function of the size of the aperture. Adjacent to the first order rays and further from the zero order would be the second order of diffracted rays. The zero order principally is responsible for providing the illumination used for the background in brightfield applications. The diffracted rays carry the information about the sample's structure. It becomes the job for the microscopist to direct as many of the diffracted rays into the objective as possible. The greater the acceptance angle of the lens, the easier it becomes to collect the diffracted rays. It is possible to see the diffracted rays at the exit pupil of the objective in the body tube.

NA defines the highest image magnification that an objective can produce before an image will begin to lose visual crispness. This is evidenced as a condition where the magnification creates only space and not structure. The magnification where detail starts to diminish is called *empty magnification*. Predicting where empty magnification begins is accomplished by multiplying the NA of the objective by 1000. Magnification is a multiplicative process and empty magnification should take into account for the final publication magnification. It is not simply a number when considering the best magnification at capture.

$$\text{Empty magnification} = \text{NA} \times 1000$$

22.38.4.10 Objective Corrections

Another inscription found on an objective's barrel—an indicator of optical quality—is the degree of color and spherical aberration correction that the objective has been corrected for. Common objectives or general-purpose objectives would be characterized as achromatic or achro objectives. A higher-quality objective would be a fluorite (fl) objective, while apochromatic (APO) objectives would be considered the highest quality objectives available. Achromatic objectives are the most common objectives and represent the highest percent of all objectives sold. Achro objectives will not have ACHRO inscribed on the lens barrel. Achro lenses are spherically corrected for green and chromatically for blue and red. Additional improvements can be made to achromatic lenses by adding fluorite to the glass. A fluorite objective will optically perform better than the achromatic lens but not as well as an apochromatic objective. APO objectives will have a noticeably higher NA. The cost of a fluorite or an APO objective will be higher than an ACHRO lens. Having a higher NA leads to more optical resolution and in the case of an APO objective, better visual crispness displaying a high degree of color accuracy, too. Apochromatic objectives are spherically corrected for two colors and chromatically for all three colors. Another color correction that has found its way into objectives is VC or violet corrections. A typical NA of an achro 10× would be 0.25, a similar fluorite lens would have an NA of 0.30 and an APO objective would be 0.45.

Other numbers found on the objective will refer to the instrument's optical body tube length requirement and whether the specimen should have a cover glass between the objective and sample, or not. Most contemporary instruments use infinity (∞)-corrected objectives; however, in the not so distant past, 160 mm was the standard. The Royal Microscopical Society proposed a tube length standard of 160 mm, and this lasted for more than 100 years. Infinity (∞) objectives have advantages because the same objective can be used for many applications such as phase contrast, brightfield, and DIC (differential interference contrast). Infinity-corrected objectives focus at infinity. They use longer working distances and allow the insertion of optical components such as lenses or filters into the optical path at many locations.

Using an objective in a manner that is not consistent with its design can affect the quality of the characteristics of the images that are produced. This incompatibility often leads to the creation of aberrations or other diminished visibility issues. If the objective has been designed to examine subjects using a cover slip, it will have 0.17 on the barrel. If the lens works best without a cover slip, it will have (−) or 0 inscribed on it. Looking at samples not matched to the lens design will produce soft and low contrast images. A coverslip and sample will all become part of the optical system in total.

Spherical aberration is a condition where light is refracted differently in the middle of the lens than in the outside areas, resulting in low contrast and haze that comes from a single location in the sample. At lower magnifications, this can be easily managed by creating more contrast by using the aperture diaphragm or during image processing. At higher magnifications, the problem is more severe and may not be managed. Photographing using incorrect coverslips will cause spherical aberration. Cheating when using a lower magnification is possible, and the loss of image contrast can be reconciled in image processing software. Coverslips come in many thicknesses and materials. Plastic cover slips will absolutely degrade an objective's performance. The component of least optical quality will have the most negative influences on image characteristics from the system.

22.38.5 Fundamentals of Operating a Light Microscope

Operating a microscope is not overly complicated; however, to gain more efficiency and improve image quality, some sequence of steps are required using long established protocols. When first turning on a microscope, select a brightness that is comfortable for viewing. It is easy to change the brightness of the lamp and not affect the optical performance of the microscope. How to adjust a microscope's brightness will be specific to each microscope. Adjusting the brightness is an acceptable practice for viewing; however, it is not suggested when imaging. Brightness can be reduced using the microscope's voltage or by using of neutral density or polarizing filters. Gray polarizing filters are preferable to brown for this application. Some photomicroscopes may have a symbol that can be used as the brightness setting for imaging. It often appears as a small camera icon. This setting was most useful for film photography but can also play an effective role in standardizing the bulb's color temperature for imaging. Once established, it remains important not to change the lamp brightness if you are using tungsten halogen lamps during the imaging session. Consistent and easy-to-manage color will be produced when not changing the color temperature of a tungsten halogen lamp.

If your microscope has LED bulbs, they are a different technology and can have their brightness changed without creating large variances in color reproduction. Bulb brightness changes lead to only small variances of colors. LED sources are of two types: continuous and pulsed. If they are of a pulsed type, their brightness can be changed and there will be no color change. If they are of the continuous type when they are dimmed, their color will change slightly but only by a small amount and almost negligible.

22.38.5.1 Setting the Eyepieces

When looking into a microscope, it is useful to focus the microscope using your dominant eye and set this eyepiece diopter to the 0 or neutral position. The image visible to the dominant eye needs to be brought into sharp focus using the microscope's focusing knob. Once focused for the dominant eye, it will be required to bring the focus of the image for the non-dominant eyepiece into focus using the eyepiece diopter lens. By focusing and adjusting things in this fashion, both eyes will have the same focus. Viewing eyepieces are not usually designed to be of the highest imaging quality and should not be used for imaging unless there is no other option. The eyepieces may degrade certain aspects of an image because frequently they have not been corrected for aberrations or flatness of field. Never assume the eyepieces to be properly adjusted when sitting down at the microscope.

22.38.5.2 Focusing

Once the brightness has been adjusted for comfortable viewing, locate the microscope's focusing controls on the side of the microscope. They will be near to the rear of the microscope and below the stage. There are typically two large knobs on the chassis of the instrument used for focusing; however, many research microscopes can be focused by using the computer or auxiliary control panel. One knob will control the coarse focus and the other (usually a smaller knob) will control the fine focus. Using either hand (whichever is more comfortable), rotate the coarse focus knob and observe what happens to the stage. This adjustment will make the stage go up and down. It can be very useful to know the travel direction up or down when the focus knob is rotated clockwise or counterclockwise. *The stage* is the large rectangular plate where the slide is located. By rotating the focus knob, the distance between the front of the lens or objective to the subject is changed. This distance is called the *working distance*. The fine focus is capable of moving the stage in single micron increments with the smaller knob and can be useful in measuring thickness of samples. By focusing on the top of the sample and referencing the number on the fine focus knob and focusing to the bottom of the sample and referencing that number, the difference can be determined in μm mm. The difference between the two values can be multiplied by the refractive index of the material that surrounds the sample. A common mounting media would have a refractive index of 1.53.

22.38.5.3 Very Small Working Distances

It can be very practical to know the stage travel directions without having to look. This can be learned by moving the front lens as close to the glass slide as possible by adjusting the coarse focus and watching the objective move toward the sample from the side of the microscope. Rotate the focusing knob to make the subject move away from the objective lens. Perform this task several times while looking at the stage not into the binoculars to become familiar with your instrument's travel directions.

Knowing which way the stage moves when the focus knob is rotated allows users to focus without the fear of driving the objective lens into the sample! When possible, always focus the image by increasing the working distance! This will move the subject further from the lens. It may require moving through several rotations of the knob to become familiar with this process and travel direction. Important samples will not be broken if this approach is used.

22.38.5.4 Interpupillary Distance

The distance between pupils is unique to each person and good microscopes allow this distance to be adjusted for an operator. The name given to this "distance" is the *interpupillary distance*. It is easy to measure this distance using a ruler, but a microscope is equipped to easily manage the number for an operator. Using both hands, grasp the tubes where the eyepieces are located. These tubes move inward or outward. Look into the microscope and move the tubes until both images are seen as one. You may have to do this a few times. An average IP distance is between 59 and 69.

22.38.5.5 Looking into the Body Tube

Grasp one of the eyepieces and gently pull it out from the microscope. This will disconnect the eyepiece from the microscope. With the eyepiece removed it is possible to see into the body tube. The microscope must be turned on. Looking inside the microscope tube where the eyepiece was located with the microscope on will display the light within the tube. The body tube is the pathway where light travels from the objective to the eyepiece. The microscope's body tube acts to block stray and ambient light from entering the microscope. This allows the image characteristics to be well defined and maintain good contrast. The aperture diaphragm will also be visible at the exit pupil of the objective and visible at the bottom of the body tube.

The length of the tube was initially a prescribed distance and necessary for correct image formation before infinity objectives became the universal technology used in contemporary microscopes. Specifically the mechanical tube length was very important in older instruments, and 160 mm was a common tube length. Contemporary objective lenses have been designed to work at specific distances from the microscope's eyepieces. Most contemporary transmission light microscopes use objectives requiring a mechanical tube length that is now ∞ (infinity) corrected.

22.38.5.6 Nosepiece or Turret

The location where the objective lenses join the microscope is called the nosepiece or turret. Often there are four or five objective lenses mounted there. The nosepiece rotates in a circular direction. Each objective is properly engaged when the objective clicks or locks into place below the prism. Microscopes can have either a rear loading nosepiece or a front-loading nosepiece. Front loading turrets allow users to see the objective at the front of the instrument rather than in the rear of the turret, which can be more difficult to access. A few companies still produce front-loading nosepieces; however, rear-loading nosepieces are more common. Turrets can be rotated from the computer on advanced photomicroscopes but can also be very simple and removable from the microscope for cleaning and service.

22.38.5.7 Substage Condenser (Height) Adjustment

A substage must be adjusted during operations and on the side of the microscope and adjacent to where the substage condenser will be located a small knob similar to the focus knob. This knob will allow the condenser to be moved up and down. It is important to locate this knob and understand how it operates. The substage condenser should move up and down. It is critical to adjust the height of the condenser when establishing proper illumination. This adjustment allows an operator to move the substage condenser at the right height for each objective and its particular magnification requirements. Setting the proper height controls the cone of illumination the condenser produces.

22.38.5.8 Setting the Field Diaphragm or Field Stop

An important diaphragm located in a microscope is the field stop or field diaphragm. Either term is accepted. The field stop is situated in the base of a biological instrument and directly below the substage condenser. The field stop controls the diameter of the illumination beam and controls the width of the beam of illumination that enters the substage condenser. There is an adjustment mechanism located near to the field stop that changes the field stop's size or diameter. The proper diameter is determined as a function of the objective's requirements and is related magnification. The field stop only controls the diameter of the illumination and not image brightness. Opening or closing the diaphragm causes the diameter of the illumination to change. If the field stop is too small, it will encroach into the image. If the field stop is set too large, this can lead to the creation of flare light. Flare can influence image contrast (Fig. 22.26).

22.38.5.9 Light and Lamps

Located typically in the back of a microscope is the light source or lamp. It will probably be a tungsten halogen lamp although LED bulbs are becoming increasingly common. An advantage of a tungsten halogen bulb was that it maintained its color temperature for life when compared to a tungsten bulb. A halogen bulb has a life expectancy of several hundred hours. Precise and standardized color temperature was more important when scientist photographers used silver halide films. This type of bulb produces a very bright and continuous spectrum over the life of the lamp. Many new microscopes come with equipped with LED technology. LED lamps can last for years; however, they are more expensive. Their color temperature is more constant than tungsten halogen lamps.

It is always useful to know where the lamp is located on the microscope and determine how it is attached. Take note of where the screws are located on this housing. Bulbs will have a long life expectancy but may need to be changed at one time or another. A bulb may be character-

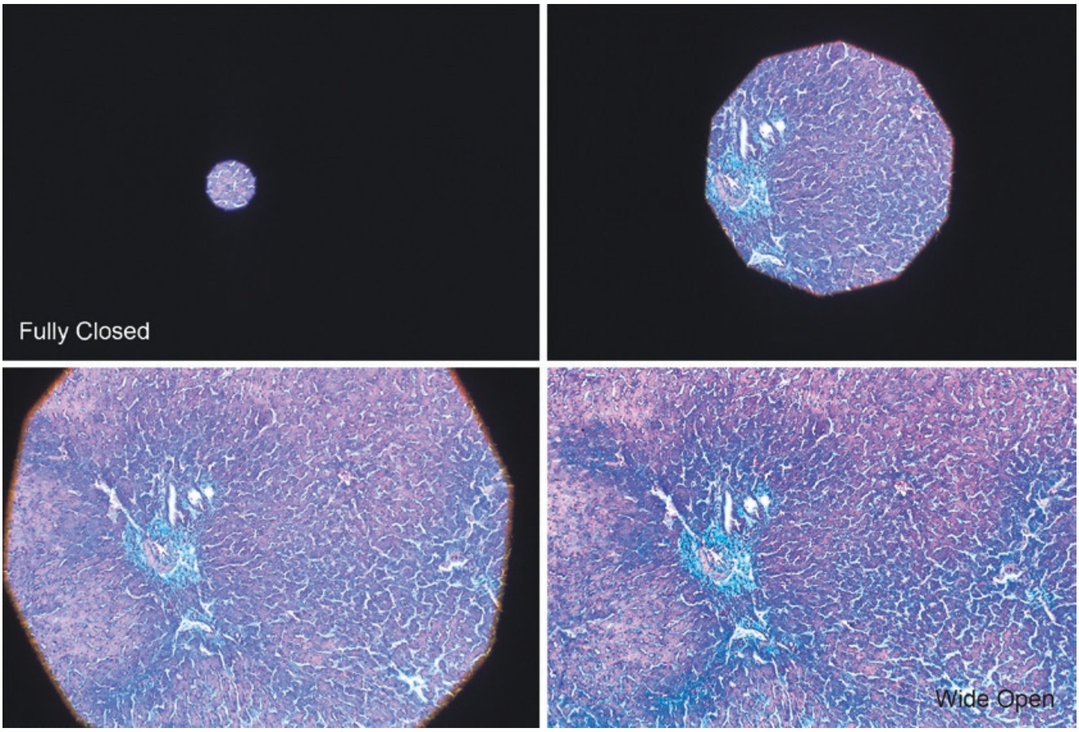

Fig. 22.26 The field stop controls the diameter of illumination but not its brightness. In the top left image, the field stop was completely closed and exhibits the same brightness that the image situated in the bottom right includes. (Image courtesy of Routledge/Michael Peres)

ized by its brightness and the spectrum that it emits. Bulbs also have a color temperature. The color temperature is shared using Kelvin degrees. 3200 K was the ideal color temperature for silver halide photography. Color temperature does not play as a critical role in digital photography but should not be overlooked as an important component to imaging outcomes. The bulb's brightness can be controlled by a switch. When adjusted, changes in bulb color temperatures will occur. Operators should use care when touching tungsten halogen bulbs because doing so will leave finger oils on the lamp, which can lead to problems over time. It is useful to wear gloves or handle the bulb using tissue paper.

Fluorescent illuminators are different and may use a xenon, sodium, or mercury vapor lamps. These bulbs are very expensive and have a recommended length of usage. LED light sources are making inroads into the fluorescence lamp product lines too. They are, in some ways, very practical because they can create customized excitation spectrums that can have real advantages for exciting specific fluorophores.

22.38.5.10 Aperture Diaphragm

The aperture diaphragm (AD) is the "steering wheel" for radiated energy (or light) in a microscope. It is a powerful control. Located in the substage condenser, this diaphragm controls the contrast, resolution, depth of field, and the brightness of the microscope's image. Operating this diaphragm is crucial to forming the best image possible. Keeping the diaphragm wide-open leads to an image with more resolution, as well as less DOF and contrast. Fully closing the AD will produce an image that has a lot of contrast, significant DOF, and poor resolution. The diaphragm's setting for each sample will be different and more about how to establish the best setting will be shared later. The aperture diaphragm, because of where it is located, will also affect image brightness but should NEVER be used to adjust image brightness.

22.38.5.11 Establishing Proper Brightfield or Köhler Illumination

Creating illumination that is uniform and creates/maintains structural information about a sample was first proposed by August Köhler in 1893. Managing the widefield illumination in a transmitted light microscope remains an important variable required for achieving high-quality images. Variances in illumination can be a problem when photographing because any differences in illumination will be amplified by the camera and image. Since a pixel records data either as off or on, illumination errors will exaggerated by a sensor. Achieving Köhler with lower power magnification is more challenging than for higher magnification applications. Today, some imaging software can correct for illumination errors. The software feature is called shading correction.

Steps required for Brightfield of Köhler illumination are the following:

1. Turn on the microscope and set the interpupillary distance (IP).
2. Adjust each eyepiece diopter as required starting with the dominant eye which should be set to the zero or *N* diopter setting.
3. Focus the image by changing the working distance using the dominant eye. Next focus the eyepiece diopter for the non-dominant eye to bring both images to the same focus.
4. Close the field stop fully.
5. Using the substage condenser, focus the image of the field stop at the specimen planeuntil the blades are well defined and at the same plane as the focused image is.
6. Center the image of the field stop using the substage condenser centration screws. The centration should be visible in the field of view.
7. Open the field stop until it just leaves the field of view.
8. Set the aperture diaphragm to the correct setting. This will be further explained.

When changing objectives, it is required to re-establish Köhler. Typically once established, changing of magnifications will require only minor corrections.

22.38.5.12 More How to When Setting Up Köhler Illumination

1. Set the interpupillary distance

   It is important to establish a comfortable viewing brightness. Once this has been accomplished, look into the microscope and set the interpupillary distance by adjusting the eyepieces. It is important to create two concentric images that are visible in each eyepiece to appear as a single image. Adjusting the height of the chair and locating your eyes directly across from the eyepieces without effort should also be a part of this beginning if possible. The eyepiece diopters should also be adjusted for an operators eyes often to their neutral position. Once an image is focused, adjust the non-dominant eyepiece adjustment.
2. Focus the image of the subject

   Bring the image into rough focus. Once the rough focus has been achieved, and using the fine focus control, critically focus the microscope. Make sure the substage condenser is set to the highest setting or most near to the sample, when performing this step. Once you have established these conditions, it may be necessary to re-adjust the eyepiece diopter settings.
3. Close the field stop (FS)

   Operate the field stop control and close the field stop (FS) until it is at its smallest size. This should be done while looking into the microscope; however looking into the microscope is not necessary. Depending on the state of the microscope's alignment, you may not be able to see anything, or the image of the FS will be clear and visible. In either situation, operators may need to close the diaphragm slowly and continue to make minor adjustments while proceeding. These adjustments will include centering the image of the FS using the substage condenser. In this step, the objective is to keep the image of the field stop visible at all times.

4. Focus the image of field stop

   Grasp the substage condenser focus knob, and move the condenser up and down until an image of the field stop is sharply defined in the oculars. The image will be focused when the edges look very crisp and black when focused by condenser. The sample's image MUST also be remain sharply defined when the field stop image is sharply defined. You may notice color fringes (red or blue) at the edges of the FS. This indicates the presence of some chromatic aberration from other optical elements in the instrument. Chromatic aberration is a lens deficiency where the various spectral components RGB are all brought to focus in different locations. Depending on how out of align the field stop is, this step of focusing the field stop image could be easy or challenging.

   Achieving parfocality of the specimen and the image of the field stop may be a bit more difficult in some situations depending on the state of the alignment or the sample thickness. Parfocal describes a condition where all the images are in the same plan of focus. It may require that you move very slowly making small adjustments, e.g., the closing of the FS or minor height adjustments to the substage condenser. Be patient and closely study the field of view to determine the location of the field stop relative to the edges of the field of view. Once the image has been successfully located, it may be advisable to begin to center the substage condenser, which moves the image of the field stop. Move the substage condenser using the centration tool typically located just below or on a bracket that will hold the substage condenser under the stage. Make the adjustments gradually and observe what happens to the image of the field stop. Move the image of the field stop roughly into the center of the field of view.

5. Center the image of the field stop

   Locate the centration adjustment screws on the condenser assembly and look into the microscope. Adjust each of these screws individually or together. Move the image of the field stop into the center of the field of view. If the image of the diaphragm is crisp, this condition will have been established; if not, you may have to go back through each of the subsequent steps prior to this point to accomplish this. The goal is to achieve a focused and centered image of the field stop that is superimposed over the focused image of the specimen when looking into the eyepieces.

6. Open the field stop until it just leaves the field view

   Once the image of the field stop is focused and centered, the final adjustment can be a bit finicky. Looking into the microscope and grasping the field stop, begin to open it. Bring the field stop to the edges of the field of view, assessing the centration of the image of the field stop to the edge of the field of view. If additional centering is needed, using the substage condenser assembly knobs, finalize the adjustment. Once truly centered, open the field stop until it is just outside the field of view and is not encroaching into the field of view. Sometimes this setting will be different for photography than for viewing. It is best to adjust the field stop for the imaging system requirements. You may also notice the image of the field stop will get less defined as it is opened. Focus should be assessed based on the central region of the field of view and not the periphery of the field.

7. Adjust the aperture diaphragm

   Establishing the correct aperture diaphragm setting is probably the most important adjustment an operator can make. The next few paragraphs will describe how to create the ideal setting. The aperture diaphragm is located in the substage condenser but visible in the body tube when an eyepiece has been removed. By adjusting the aperture diaphragm (opening and closing), it can be observed as it moves in the tube with an eyepiece removed. It can be very useful to move the diaphragm through its entire range and observe the brightness and location changes.

The goal is to have diaphragm partially interject itself into the body tube. When the diaphragm is all the way open, the diaphragm is not visible in the body tube, and when the diaphragm is all the way closed, it is may cover more than 50% of the tube's diameter. A general starting point for the diaphragm location would be where the AD is visible in the body tube and where 80% of the tube is open, and where 20% of the tube is covered by the aperture diaphragm. If the AD is outside of the tube, it will have NO effect on image formation, and if the AD is closed to its smallest size, it will create significant contrast, increasing the image's DOF and diminishing image resolution.

The proper use of the aperture diaphragm will significantly influence the characteristics of the image. These attributes include an image's DOF, brightness, resolution, and contrast.

To observe how the aperture diaphragm controls resolution, contrast and DOF, set up a microscope using proper Köhler illumination, and use a 10× objective. Select a microscope slide of a subject that has easy to see structural details. It is important not use a weakly stained sample for this assessment. Remove an eyepiece and observe the aperture diaphragm moving in the tube at the exit pupil of the objective. An image of a bright disk of light and an image of the aperture diaphragm at the periphery of the tube should be visible when moving the AD though its range. Grasp the aperture diaphragm, look into the body tube, and rotate the diaphragm and observe the operation of the diaphragm in the microscope.

It should be noted that substage condensers also have a numerical aperture. When the image of the aperture diaphragm in the tube is set so that its edge is at the edge of the body tube, its numerical aperture is matched to that of the objective. This is not always desirable, but a useful starting point for the creation of contrast, resolution, and DOF. The diaphragm will have minimal if any effect on image formation when at its NA matches the NA of the objective. Only when the diaphragm interjects itself into the illumination pathway will image enhancement or degradation occur. Put the eyepiece back into the microscope.

The aperture diaphragm plays a critical role in controlling the characteristics of image formation. The four image attributes are controlled by the aperture diaphragm are:

- Image contrast
- Resolution
- Depth of field
- Brightness

The aperture controls these four outcomes by controlling the microscope's diffraction. The degree of diffraction required to optimize an image will be influenced by a subject's characteristics. Blood cells, for example, do not experience any change to the above mentioned image attributes from the use of the AD; however, other samples are noticeably degraded (Fig. 22.27).

The proper setting for the aperture diaphragm will be subject dependent and based on visual judgment and personal taste. A person just learning about microscopy will need to take the time and practice seeing diffraction to become proficient in mastering the power of observation. It is very easy to see contrast; however, it is not easy to see resolution.

Relocate the eyepieces in the body tube and grasp the aperture diaphragm when looking into a microscope. Rotate the diaphragm through its entire range refocusing as necessary. Study the effects of the diaphragm very closely by examining tissue boundaries within a sample. Critically focus. You may need to continue to re-focus throughout the evaluation of how much contrast, resolution, and DOF the sample requires.

As the diaphragm is closed, the image will get darker, possess more contrast, and demonstrate more depth of field. As the diaphragm is more open, the image will get brighter and exhibit less contrast and less depth of field, but it will have more fine detail or resolution. Somewhere in this range will be the ideal setting for the specimen being examined. Every subject will have a different requirements for the creation of optimal results. Go through the diaphragm range again and observe the fine detail. Be careful not to perceive contrast as resolution and detail. It is quite easy to add contrast to an image during image

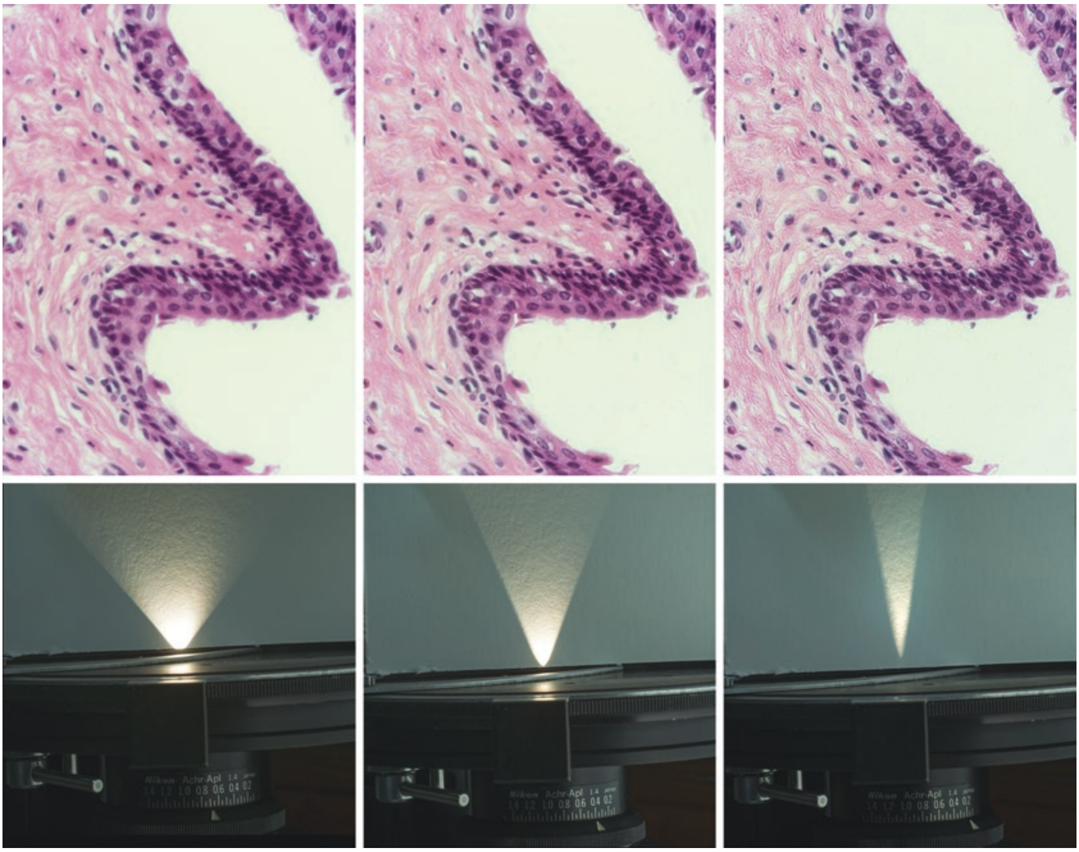

Fig. 22.27 In these three photographs, the aperture diaphragm has been set to three different locations. The photographs were each made using a 10× Fl—NA 0.45 objective and an achro aplanic substage condenser, NA 1.40. The photograph on the left was made with the aperture in its maximum opening for the 10× lens (NA 0.45) creating the maximum resolution and the least amount of contrast. Notice the angle of light leaving the condenser. The middle image was made with the NA set to approximately an NA of 0.3, which created the optimum balance between the contrast and resolution potential for the objective. Notice the angle of the light becomes smaller when the aperture diaphragm is closed. The image on the right has the most contrast and least amount of resolution as a consequence the aperture being nearly closed to its smallest setting at an NA of 0.15. The angle of light is also the smallest when operated in this position. (Image courtesy of Routledge/Michael Peres)

processing, and it is much more difficult to form optical resolution.

Open the diaphragm and begin to study the effect of the diaphragm as it is opened. Locate a setting that seems to balance the sample's contrast requirement and fine detail requirement. Once achieved, imaging can begin. Sometimes for new users, it can be helpful to make a series of photographs using numerous aperture diaphragm settings until greater proficiency has been acquired. Image brightness will be affected when adjusting the diaphragm.

22.39 Photographing

Making photographs using a light microscope is not an overly complicated subject. The formation of highly resolved images represents a bigger challenge for photomicrography than actually taking the picture. Software and the sophistication of the modern cameras have made the process efficient and simple. The last part of this chapter will address the use of dedicated instrument cameras and DSLR cameras for photomicrography.

22.40 Instrument Cameras and Operating Them

These are ideal for use on a photomicroscope. Designed specifically for a microscope, they are sold with camera controller software such as Zen® from Carl Zeiss Microscopy or Elements® from Nikon. A camera and its corresponding software can be a powerful tool useful in the recording of more data than the eye can see. Any camera used on a microscope must be able collect image photons, record light as variances of brightness, and record the image as grayscale needed to create color images based on information collected at each pixel (RGB). The camera will have a shutter that may be a source of vibration, and no matter how basic, the camera will need to be able to measure the light needed to create the correct exposure.

Instrument cameras offer some advantages when properly matched to the output needs of users. They are very compact and typically offer various features across different models ranging from very basic camera useful for common brightfield applications or very sensitive low light high-resolution cameras useful in fluorescence and other challenging applications. The basic features of these cameras include preview or live view, exposure modes of manual or automatic, exposure adjustment controls, sensor sensitivity adjustment, gain, binning, digital resolution pixel (megapixels), white balance controls, image contrast capture mode, or input dynamic range. Some cameras may have a spectral response or color adjustment features, bit depth setting, and other image adjustable features such as sharpening. Higher-end cameras can measure and perform basic image analysis functions as well. It is also very common to have video capabilities.

Once an image has been properly formed, it can be captured. All camera controller software must be launched prior to using the camera. Given the wide range of products and operating systems, it is impossible to share any particulars for cameras sold by Zeiss®, Olympus®, Leica®, Nikon®, Hamamatsu®, or Spot Instruments®. Only the fundamental and universal controls can be discussed in this entry.

Once the image has been directed to the camera and camera controller software is initialized, it is time to focus using the live view or preview. The camera can be operated in fast focus or slow focus mode. When used in fast focus, typically half of the camera's pixels are used for the focusing. The still image will not be adversely affected using either the fast or slow focus modes. It may be impossible reshoot a sample, so creating the proper pixel resolution is an important decision the scientist photographer must make separate from the pixels used for the focus mode. When time is a crucial fact, fast focus makes sense. When time is not a factor, slow focus—while a bit less responsive—will create images that will most resemble the recorded file. Microscope cameras come with many resolutions bits per channel. Some cameras are equipped with microstepping motors allowing them to make multiple recordings creating more highly resolved stitched digital files. DSLR cameras will frequently be able to create higher-resolution files when compared to instrument cameras. A full-sensor camera such as the Nikon D810 creates more than 7000 pixels in the wide dimension and a 12- or 14-bit file.

Once the focusing mode has been selected, the exposure mode must be selected. There are only two modes of operation for instrument cameras—auto and manual. A DSLR will have an additional setting for program mode. In the manual mode, the operator selects the proper time increment needed to create a correct exposure. The time will depend on the sample's brightness and other factors that affect the microscope brightness. Seeing the image and histogram in the camera preview mode will provide for the operator the information about the accuracy of the time. In the manual mode, shorter times will make the image darker, and longer times will create images that are brighter. Manual mode can be very effective when working in fluorescence applications for tighter controls. There is more about cameras, shutters, and exposure in Chap. 4 (Fig. 22.28).

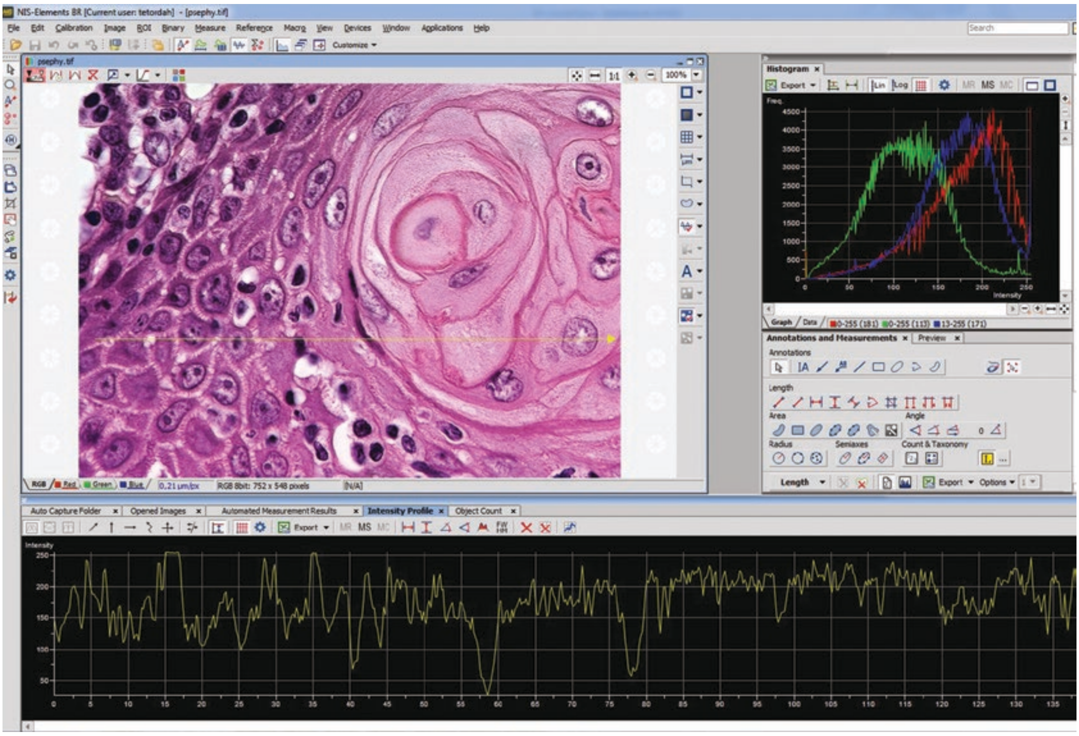

Fig. 22.28 A photomicroscope's camera software is noticeably different than the menus used in a DSLR camera. This illustration reveals the appearance of a screen from the Nikon Elements® software. (Image courtesy of Routledge/Michael Peres)

22.41 The Photographic Exposure

When the camera is operated in the automatic mode, the basic exposure that the camera makes will be determined using a brightness reading that creates an 18% gray tone. The information provided to the user for this average exposure would be indicated by *N*, normal, or 0 setting. For brightfield microscopy, it is suggested to increase the autoexposure using the software's exposure compensation control. A normal adjustment would be +1 or +1.5 E.V. (exposure value) for brightfield microscopy using a sample with average thickness and contrast. When working in darkfield illumination, for example, the exposure compensation would be −2.0. Using the preview mode will be a useful tool for identifying the best exposure. It is important to base exposure judgments on the brightest region of the sample. Viewers will be more accepting of regions that are too dark in a picture than regions that are too bright and overexposed. An ideal exposure has detail in the bright and dark tones. Sometimes these adjustments are accessible by moving regions of the image displayed in the camera's software.

Sample contrast will play a role in the creation of the correct exposure. If the sample is very thin or weakly stained, a good exposure will use different times than if the sample is thick and densely stained even when using the same microscope brightness settings. The sample's internal visibility or contrast is a function of the sample's thickness, the stain darkness/concentration, and the type of stain. To make better images, it is helpful to profile the capture contrast or to modify the gamma of the sensor in the camera to the sample's characteristics. Some cameras will allow contrast to be changed in different ways. Samples that are thin and weakly stained will benefit from a sensor setting having an increased contrast or gamma. For samples that are densely stained and thick, it is useful to select a low contrast setting. This feature will be located in the camera's software will be described in different ways. Modifying the shape of the image's histogram in the LUT or look up table is one common method to do this. Scene choices provide another way and might be include fluorescence, brightfield, darkfield, H & E, or high, medium, or low. Carefully selecting exposure and contrast settings is an enormously important step and needed to record the maximum data about a sample.

When learning how a camera operates, it might be useful to create an imaging or exposure test to evaluate with how the various software's tools operate. When learning new software for a new microscope or camera, a good exercise is to create an exposure series going from −2, −1, 0, +1, and +2 using a typical sample and changing nothing else. It can be useful to make a series of exposures using the various contrast settings with the optimal time determined from the exposure series. The more experiences gained in establishing camera's settings for various samples, the more information will be possible to be recorded. This in turn makes more information available for image processing as needed. The better the recorded image, the lower the noise, and digital artifacts will be in that file as well.

A camera's color reproduction is a separate characteristic than a camera's white balance. Both can be changed. White balance describes the process of equalizing the data in a white target from the scene that has equal units of RGB information. When considering a brightfield microscope, the clearfield or background is an excellent and uniform target to use for white balancing. Measuring and calibrating the sensor to this value can be useful for the creation of standardized views overtime. It is possible to apply white balance by averaging the whole scene or measuring a specific number of pixels in a region using the software eyedropper. For brightfield images, a white point brightness of 240 in the RGB pixels is ideal. When averaging, no part of the stained tissue can be located in the illumination pathway. The tissue must be moved back and forth determine the best white balance. Whatever method is selected, it is operator preference, and in the end, so long as the process is managed and not random, effective photomicrographs can easily be reproduced time and time again.

The amount and the purity of a color that is reproduced is often equated with image saturation. Every sensor responds to color data in similar but different ways and based on the characteristics of the filters used on the pixels and the imaging software. There will be variances across brands and models even within a single company. Certain colors will reproduce with increased saturation or purity, and other colors will be more correctly reproduced. When a sensor is more responsive to certain spectrums, adjacent pixels may be involved during exposures or capture. Decreasing color contrast or saturation is also an important tool for the recording of useful and precise image data. Some cameras will characterize saturation as color contrast. Proper selection of this capture attribute can assist in the purity of the image signal that is recorded. Sometimes when adjacent pixels are affected by minor exposure errors or increased color saturation, the image outcome referred to as blooming. Blooming is characterized by pixels sharing exposure information with neighbors. Desaturating or diminishing exposure at capture can best manage this outcome and control how the volume of color contributes to seeing more.

In certain situations, there will not be adequate brightness to make a good exposure. Unlike DSLR cameras that can have their sensitivity adjusted using the ISO control setting, instrument cameras are not adjustable in the same way. To change a sensor's sensitivity, the GAIN tool is used. Increasing GAIN will cause the sensor to become more sensitive to light. Using too much gain however will cause the production of digital noise in the image. Because of the potential to create this image artifact, increasing the camera's sensitivity should be chosen when other considerations for making a brighter image are not possible. Sometimes there can be other ways to manage microscope brightness once there can be no more increase to the lamp brightness. If neutral density (ND) filters or internal polarizing filters are in the optical path, they might be removed. If gain is required, select the lowest possible gain setting that creates a useable result. It is best to inch toward a solution. Experience will be a great teacher.

Another way to increase the camera's sensitivity is through the use of binning. Binning is the grouping of pixels together to act as one. By grouping pixels together, the individual pixels act like one large image sensor. Larger pixels collect more light and create exposures needing less light or signal. The disadvantage of binning is that the number of pixels that makes up final file will be lessened by the factor of the binning that was selected. For example, if a sensor has 1800 pixels in the long dimension and the camera is set to the 2 × 2 binning selection or four pixels and the binned file will be 450 pixels, not 1800.

Many instrument cameras offer some basic but useful features that include the ability to annotate images, add magnification bar scales, and perform basic image processing. There are also many filters that can be selected for use at capture such as sharpening. Annotating can be very useful for later use and so can be the addition of the bar scales placed into image files. It is important to keep in mind that any image processing work done on a file using proprietary camera software will not be always compatible with other image processing software such as Adobe® Photoshop or GIMP® (GNU Image Manipulation Program). Image J software may be to open some proprietary file formats but should be tested with unimportant files is suggested before finding out at a critical time. Saving image files in TIFF format is recommended. JPEG, while a universal format, will compress file data from pixels that contain similar data. Data will be lost when making JPEG files, and over time compression artifacts will be created, too. Image processing software will be more effective and precise when compared to camera capture software when used for image processing.

22.42 DSLR

Digital single reflex cameras can easily be used for photomicrography, and there are advantages and disadvantages for use for microscopy. Mirrorless cameras are also a popular type of camera and will have slightly different considerations for their use in the laboratory environment. Mirrorless cameras function in much of the same way as a DSLR but do not use a reflex viewing system and are more compact. For this reason, they have become very popular for travel and applications where the size of the camera matters. At this time, mirrorless camera does NOT offer unique applications for use in a laboratory environment and DSLR cameras seem to be more prevalent.

22.43 DSLR Camera Advantages

There are many camera settings that can be used for optimizing the sensor's recording features. These include:

- Variable ISO and noise management choices
- High resolution pixel counts for lower costs
- Portability and ability to use the camera for other imaging applications
- Color reproduction and color management choices
- Various File Format choices including RAW
- Live View and video capabilities of high end cameras
- Bit depth

DSLR Camera Disadvantages:

- Mirror creates a source of vibration when used in magnified imaging applications.
- Coupling to a microscope.
- Alignment and setting up/tear down.
- Focusing in the viewfinder.
- Changing image features using menus and not on the bigger screen of a computer.
- Battery consumption.
- Delayed shutter activation when mirror lock-up mode is on.
- Attaching and operating the camera.

How to couple or not couple a DSLR camera to a microscope is one the first considerations when moving forward with imaging. A DSLR camera can be simply hung over the microscope's photo eyepiece using a vertical copy stand or tripod with its lens removed. It is very practical to use extension tubes or bellows on the camera to act as a baffle to ambient light, required to manage flare. Ambient light in the lab can create flare and other image defects in science images. Flare will lower image contrast and create poor definition or visibility. If extension tubes or a bellows is not available, it is possible use black construction paper with black tape as substitute. The sensor will need to be carefully aligned over the eyepiece, and the sensor will need to be perpendicular to the optical axis. Using a spirit level or smart phone level app can be useful as an aid in making a good alignment. The sensor needs to be parallel with the stage. The camera should be at a distance from the sensor where the circle of illumination produced by the eyepiece is large enough to adequately cover the sensor without producing a circular image. The formation of circular images is not desirable for research but can be fun when used for artistic work. Moving the camera further from the eyepoint will increase the circle's size and subsequent image size. When moving the camera further from the eyepiece, the image will also become dimmer, and the circle of good definition will completely cover the sensor.

If a more structured system is desired, coupling the camera to the microscope will require an optical and/or mechanical couple. Many manufacturers of microscopes such as Nikon, Olympus, or Zeiss sells adapters for DSLR cameras. There are many configurations as you might imagine, and it is necessary to correctly select a coupler for a specific type of camera as well as the microscope and type. C-mounts, bayonet mounts, or other particular mounts can be suggested by a vendor. Coupling might be considered ideal; however, ensuring the optical elements in the coupler are of the right quality should be considered before purchasing. "You get what you pay for" will define the characteristics of many optical elements. Inferior optical elements will diminish image quality significantly. A full-sensor digital camera will require a different magnification than a cropped sensor camera and some couplers will have lenses, and others, will be without glass lenses.

Focusing the magnified image using a DSLR camera can be accomplished in several ways. It is possible to simply project the microscope's image directly into the DSLR's viewfinder without a lens for focusing. Seeing a crisp image can be challenging. The coarseness of the viewfinder's surface is rougher than the fine detail of the magnified image. As such, the image never appears sharp or crisp in the viewfinder because its elements are spread across a diffuse textured screen designed for different applications. It might be useful to focus using the coarse focus when using the camera viewfinder to start. It is also very important to properly set the camera's viewfinder reticle. Most brands of DLSRs have a diopter setting control near to the eyepiece. The diopter adjustment knob works as a lens switching from near to far focus. It does not affect the focus circuitry of the camera as it is after the auto-focus mechanism. It only affects how you see the image in the viewfinder.

It is possible with some cameras to focus the image using live view. This feature projects the image from the sensor directly to the computer. This allows precise viewing, focusing, and composing on the computer monitor. In a dimly lit room, this can be very helpful for precise control and location of critical definition within the sample. A small disadvantage might be that the preview window for live viewing might be smaller than desirable or when photographing dynamic events, there is a lag in the shutter release as live view shuts down. Live view can be helpful; however when the mirror and other mechanicals of the shutter system is operating, this can again become a source of vibration to the image if not carefully managed.

It is also possible to parfocalize the camera's viewfinder to the viewing eyepieces. This would create the same focus in the camera and eyepieces. This can easily be done by first focusing the image in the camera's viewfinder. Once the image has been focused in the camera, re-direct the image back to the microscope's eyepieces. Using the eyepieces diopters only, re-focus the image without changing the working distance. If done properly, both images should be in the same plane of focus.

Vibration is a very real problem in microscopy. Vibration can be produced by many sources both within a camera as well as caused by environmental sources. Vibration will make images appear not sharp. These images can be well focused and blurry because of image movement during exposure. Computers and internal fans in light sources can create vibration if they are located on the microscopy table. Fiber optic lights can also have fans built into them for cooling and can be a source of vibration. There can also be environmental sources of vibration including elevators within buildings, subways that go under buildings in major cities, and sometimes the powerful HVAC systems located on the roof of a building. Anti-vibration tables are ideal solutions to isolate vibration but are very expensive. There are vibration reduction settings in some cameras and VR lenses, which are more common. Image processing can be somewhat effective in removing some of the artifact of image shake but is not an ideal solution.

DSLR cameras themselves can be the source of vibration. Simply depressing the shutter can jar the camera and create image shake. A DSLR camera uses a mirror that allows for the viewing of the image in the reflex viewer. When the shutter is depressed, the mirror moves out of the way and the focal plane shutter opens and closes allowing the light to strike the sensor. All of these mechanical processes can have significant influences on image stability and can produce vibration. The mirror will create camera shake and the movement of the focal plane shutter also can make vibration. The effects of vibration in the image can be controlled through the use of slower shutter speeds rather than using shorter times. By using a longer time, the effect of the vibration exposure will be absorbed into the longer and more stationary exposure.

There are few things that can minimize the production of camera vibration. Triggering the camera from the computer and not using the shutter depress button directly is a good place to start. If tethered, the shutter can be activated using Adobe® Lightroom or other camera controlling software. It is also suggested to consider using the camera's self-timer. This will also dampen any vibration caused by the operator. It can be practical to use an electric remote shutter release, too. Any or all of these three approaches will be helpful in controlling vibration that is produced when firing the camera.

Probably the most useful tool for vibration control using a DSLR camera is by selecting the camera's mirror lock up feature. For mirror lock up, focusing is accomplished first and then the mirror is locked up. Once the camera has settled down, the exposure can be made. An image that is vibration free is a great accomplishment using a DSLR camera. Sometimes it is suggested to make multiple photographs of a sample using the same settings hoping that one of the files will be slightly sharper than the others.

23

Photography in Pathology and Other Procedures

Katrina Fernandez, Paola Pasquali,
and Rajendra Singh

Contents

23.1 Brief History of Photomicrography

> *Il est clair que dans un laboratoire spécialement destiné aux études microphotographiques on opérera différemment*
>
> (It is clear that in a laboratory specially designed for microphotographic studies one will operate differently)
>
> Albert Londe, in *La photographie médicale*. Gauthier-Villars. 1893.

The art and science of taking photographs or digital images through a microscope is called photomicrography. This photographic technique is widely used in science, medicine, and engineering, and photographs can be taken for scientific, commercial, or artistic purposes.

The field of pathology is driven by images, and throughout history, it had been intrinsic to pathologist's activities the need to record morphological findings, both at the macroscopic and microscopic level for diagnosis, consultation, documentation, and education [1, 2].

Before the development of photography, an early type of image projector was invented in the seventeenth century called the Magic Lantern. It was intended to enlarge and project semitransparent images painted on glass plates onto a blank wall or screen. Magic lanterns were originally used by conjurers, magicians, and illusionists. Ten years after the invention of photography, in the 1840s, the Philadelphian daguerreotypist William and Frederick Langenheim used the method for making a transparent negative on glass, previously invented by Niépce de Saint-Victor and printed that negative onto another

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plate of glass, rather than on paper, to make a positive transparent black and white image suitable for Magic Lantern projection. It came to known as “lantern slides” quickly adopted for educational and science purposes [1, 3].

In 1831, Alfred Donné, a pioneer in microscopy and hematology, received his doctorate with a thesis focusing on the use of microscopy in medicine, a concept on which traditional medicine showed clear resistance. He even invented the collapsible microscope that could fit into a coat pocket! In collaboration with Leon Foucault (1819–1868), they worked on an improvement of the Lieberkühn’s “solar microscope” and invent the so-called “photo-electrique” projection microscope in which they used an electric light as a brighter source of illumination [4].

In 1839, they used daguerrotypes to create images obtained from their microscope and published the *Cours de Microscopie, Complémentaire de Études Medicales* (Figs. 23.1 and 23.2).

Albert Londe (1858–1917) [5], a chemist responsible for the photography laboratory at La Salpêtrière, worked at the times of Jean-Martin Charcot. He used innovative techniques and invented equipment to photograph microscopic preparations, either vertically or horizontally (Fig. 23.3). The ingenious illumination system was illumination allowed him to obtain a uniform field of illumination obtained by the “heliostat” which concentrated sunlight—which he called *la lumière oxhydrique*—which did not raise the temperature of the specimen; in addition he used condensers and plano-convex lenses. In collabo-

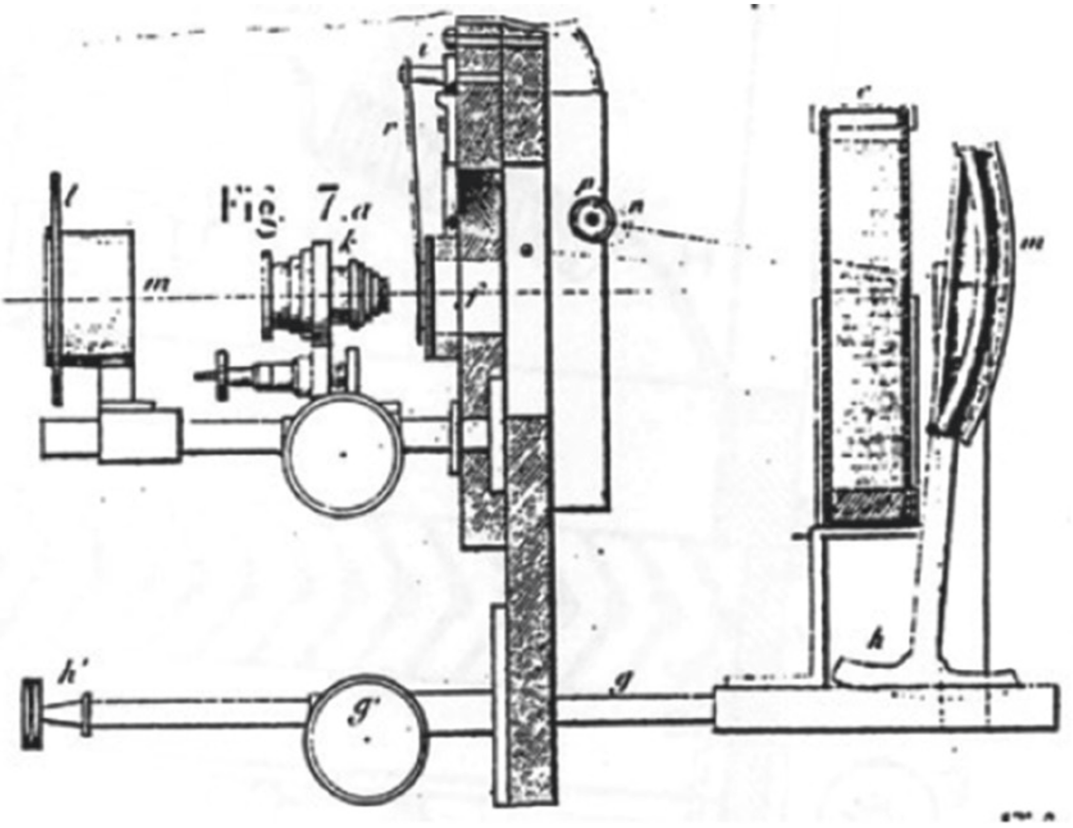

Fig. 23.1 Donné and Foucault’s photomicroscope. Illumination was supplied by a battery-powered electric carbon arc (g´) with rods vertical to the plane of the page. (From: Cameron JS. A history of urine microscopy. Clin Chem Lab Med. 2015 Nov;53 Suppl 2:s1453–64. https://doi.org/10.1515/cclm-2015-0479. Available from: https://www.degruyter.com/downloadpdf/j/cclm.2015.53.issues2/cclm-2015-0479/cclm-2015-0479.pdf)

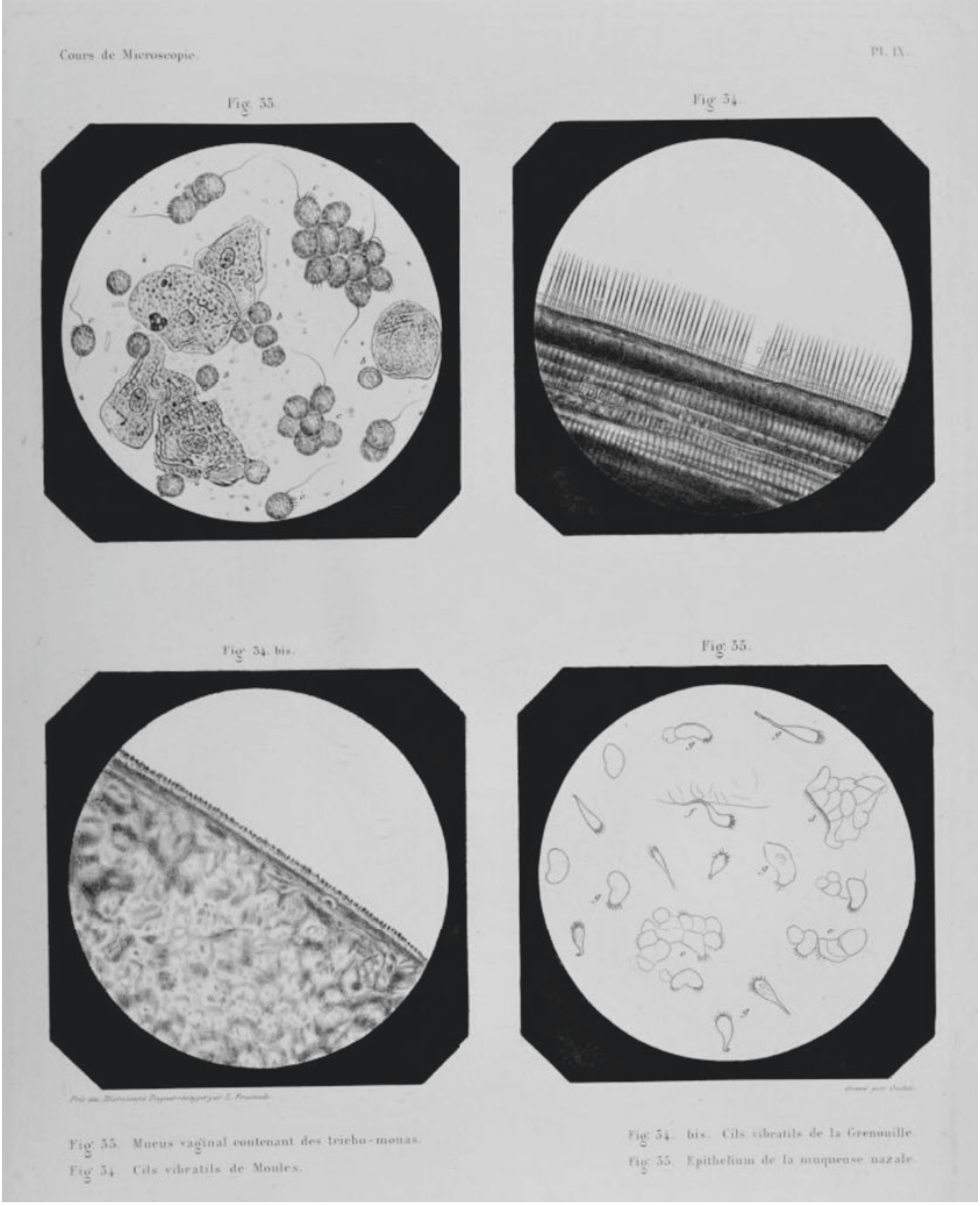

Fig. 23.2 Reproduction of daguerrotypes taken by Donné. (From Atlas Cours de Microscopie, Complémentaire de Études Medicales, Wellcome Library Collection, figures under Public Domain CCBY 4.0)

ration with Paul Blocq (1860–1896), he made the plates of the book *Anatomie pathologique de la moelle épinière* (Anatomy of the spinal cord) published in 1891 with a preface of Charcot himself (Fig. 23.4) [5].

Professor Ludwig Edinger designed one of the historic microscopic imaging-capturing devices in 1910, the Leitz Edinger Apparatus, which could be used as magic lantern slide projector, microscope slide projector, or for photomicrogra-

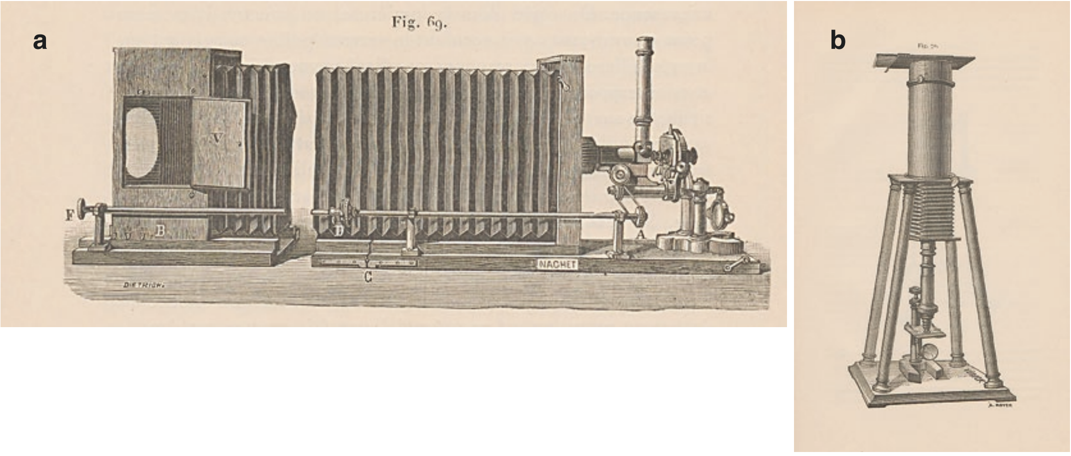

Fig. 23.3 Equipment for (**a**) horizontal and (**b**) vertical photography of microscopy slides built by Albert Londe. (Available from: La photographie médicale: application aux sciences médicales et physiologiques. Paris: Gauthier-Villars et Fils, 1893. ETHBibliothek Zürich, Rar 3693, https://doi.org/10.3931/e-rara-18614/PublicDomainMark)

phy with the addition of the 11 × 14 in. plate camera [6].

After 1935, when Kodak manufactured their first color film, multilayered film (Kodachrome) began the transition from lantern slides to color film for photographing microscopic images and its uses in lectures, teaching, and patient care. Despite the color and archival quality of Kodachrome film, this required a complicated processing procedure only available in a few large laboratories. From the 1950s to 1980s, amateurs, professionals, and smaller laboratories began using more simplified processing film (Ektachrome) for microscopic and tumor-board image preparation [1].

Many films, especially Kodachrome 25 (a 35 mm daylight-film), required full light spectrum for optimal color and image quality obtained from microscopes bulbs at maximum intensity. Microscopes were prepared with "photograph" settings that optimized image capture with 35 mm film cameras; a later development of devices included a brand specific accessory that attached the camera to the microscope [1].

Late 1990s and early 2000s microscopy image photography followed the transition from 35 mm film to digital images, eventually forcing Kodak to cease offering film processing in 2009. Capturing digital images was not necessarily simpler as digital cameras still require adaptors mounted in microscopes and specialized software and hardware [1].

During the past decade, smartphones were sold with cameras with small sensors resulting in poor image quality. Point-and-shoot cameras had two or three times the pixels available to capture better microscopic images. It was until the releases of iPhone 4 (2010) with a 5MP camera that the application of a smartphone for proper microscopic image capturing could finally be done and improved later on with ocular microscope adapters [7]. Freehand no-adapter methods and techniques have been described for smartphone microscopic photography [1, 8–10].

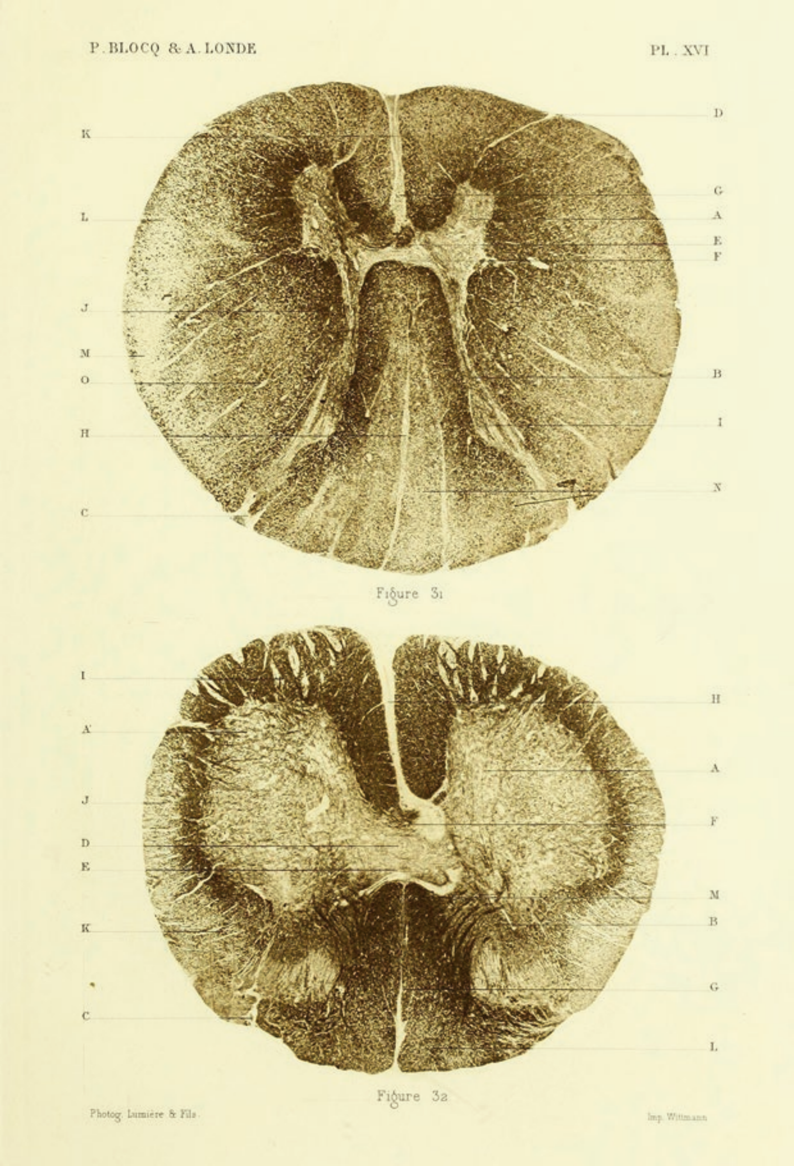

Fig. 23.4 Photograph from Anatomy of the spinal cord, A. Londe and Blocq (1891). (From: Anatomie pathologique de la moelle épinière: 45 planches en héliogravure avec texte explicatif, Wellcome Library Collection, figures under Public Domain CCBY 4.0)

23.2 Basic Concepts of Photomicrography

When referring to photomicrography, we mean photography taken through a compound microscope. These types of microscopes are bright field microscopes with two positive lenses, offering better magnification. The initial stage of magnification takes place in the microscope's objective forming a primary image that is further magnified by a second lens (the eyepiece) to produce a final image for the eye or for the camera. Taking into account this definition of photomicrography, it can be said that the minimum equipment

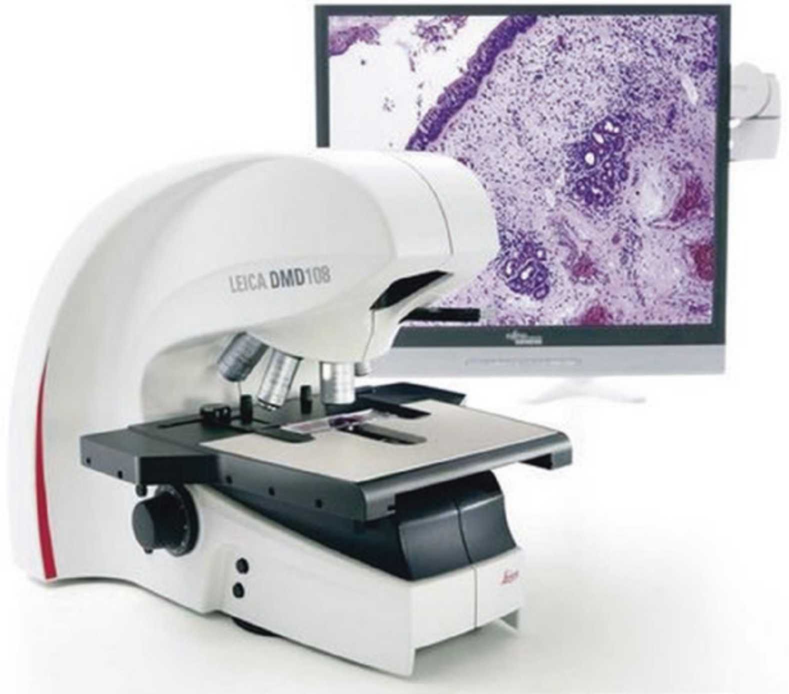

Fig. 23.5 Digital microimaging device Leica DMD108. The image is displayed to a monitor or projection screen thanks to the integrated camera. It comes with an integrated email function and remote viewing via the Internet. (Available from: https://www.leica-microsystems.com/products/stereo-microscopes-macroscopes/p/leica-dmd108/)

required for taking photomicrographs included a conventional compound microscope, a built-in or attachable camera, and the specimen to be photographed [11].

Most microscopes used in photomicrography have flat-field (PLAN) objectives and a Köhler illumination system. In addition, they should be equipped with binocular observation tubes and a third tube (the phototube) which extends vertically for the camera. A sliding mirror or a beam-splitting device directs light from the objectives either to binocular tubes or to the photographic apparatus as required. By this, the light can be directed in three different ways: 100% to the eyepieces, 100% to the camera or splited between both [11].

23.3 Types of Cameras for Photomicrography

When selecting a camera, both still cameras (film-based device or digital device that take one picture at a time) [12] and digital video cameras are suitable for photomicrography. A professional SRL-type digital camera (DSRL) with a removable lens or an integral lens “prosumer” o “point-and-shoot” camera with a good close-up capability is recommended for bright field photography, especially if the camera will also be used for gross photography. Digital video cameras are permanently fixed to the microscope and are useful for morphometric measures, low light conditions, and displaying high-resolution images on monitors. These cameras are made by the major microscope manufacturers as well as dedicated specialist imaging companies and are designed especially for microscopes and microphotography; the photographic system can be incorporated into the microscope body or be part of a substantial module attached to the top of the stand [11] (Figs. 23.5, 23.6, and 23.7).

23.4 Connecting Your Camera to a Microscope

There are several options for connecting a camera to a microscope. The camera system can either be connected via a special phototube on the trinocular head or can be connected to one of the microscope's eyepieces. "Prosumer," "point-and-shoot," and mobile phone cameras can be used for occasional noncritical photomicrography as their quality is not excellent. These cameras can simply be placed at the focal point of the microscope eyepiece, coupled temporally to the eyepiece using an adapter or adapting the camera on the trinocular camera tube of the microscope.

Fig. 23.6 Twenty megapixel color CMOS camera DMC5400 by Leica. Captures high-resolution images with 20 megapixel sensor and collects high-speed live images at up to 40 frames per second. (Available from: https://www.leica-microsystems.com/products/microscope-cameras/p/dmc5400/)

23.4.1 Eyepiece Cameras

The image produced by the microscope objective can also be passed through a reduction lens before reaching the camera sensor. This way the image produced by the microscope objective is reduced in size to better match the small sensor size of the digital camera. The reduction lens produces a real image on the camera sensor. Without the reduction lens, the image would be excessively large. The reduction lens also results in a brighter image. This is an improvement to the first point from above. Eyepiece cameras for microscopes use this system. The reduction lens is not a compensating photo eyepiece and therefore does not correct lens errors produced by the objectives [12].

23.4.2 "Prosumer," "Point-and-Shoot," or Compact Cameras

The image produced by the microscope objective is first passed through a regular eyepiece. A virtual image is then produced, which cannot be used to directly make a picture. A camera (with its own

Fig. 23.7 The high-resolution, 18 megapixel SC180 color camera from Olympus, adaptable to microscope (Left) and Olympus Image Analysis Software which enable flow of acquired images, filtering, measurement, documentation, and archive. (https://www.olympus-ims.com/en/microscope/sc180/)

objective) then picks up the virtual image and project it on the sensor. The camera works like the eye, which converts a virtual image to a real image. This system is used in afocal photography, in which a regular compact camera (with its own objective and all) is attached in front of the eyepiece [12].

23.4.3 Using a Tripod

The camera is mounted on a tripod, and the picture is taken through the eyepiece of the microscope. It is necessary to zoom in, and it is also necessary to adjust the camera eyepiece distance properly. There are some adapters available, which allow clamping a compact camera to the base of the eyepiece, without any modifications to the camera. These clamps use the tripod connector of the camera.

With this technique there is the possibility of vignetting if the system is not properly set up and the resulting image quality is not the best, mainly because regular eyepieces are not designed for photography. This means that not all the compact cameras are suitable for taking this type of pictures. Making sure that the camera objective is not larger than the exit pupil of the eyepiece is important. Field curvature can also be a problem, resulting in an image with the sides are out of focus while the center is in focus [12].

23.4.4 Using an Adapter

An adapter can be used to temporally couple the camera to a microscope eyepiece. This technique eliminates camera movement and allows for a much easier composition of the image. In general, adapters are a threaded coupling ring with a lens adapter ring. The coupling ring is threaded into the filter threads of the digital camera lens, and the eyepiece is inserted into the lens adapter and secured by turning three sizing screws. Finally, the digital camera/adapter assembly is inserted into the sleeve of the microscope eyepiece. Other types of adapters are intended to mount digital cameras on the trinocular camera tube of the microscope [1, 12].

23.4.5 Without Any Adapter or Tripod

It is possible to take photomicrographs without the need of any adapter or tripod. There are several described techniques in literature; Maude [8] described in detail one simple technique as follows:

1. Using the microscope, examine the specimen by the eye, and select the area of interest and magnification required.
2. Increase the light source to maximum intensity.
3. Hold the camera lens against the microscope eyepiece. A rubber cup over the eyepiece helps to hold the camera steady. A small circle of light will be seen on the cameras LDC screen. The eye point—location where the image exits the eyepiece—is used for imaging; place the smartphone lens or compact digital camera lens (fixed lens) at this point.
4. Use the camera’s zoom function to increase the size of the circle as required. The most difficult step is moving the camera lens small distances across the eyepiece to center the circle. The camera’s autofocus should then self-adjust to give a clear image.
5. Adjust the fine focus of the microscope to maximize image quality.
6. It the image is too dark or grainy, the camera’s ISO setting should be increase (usually 100 or 200 will suffice) or the “darkness” or “night-time” setting selected, depending on the model of the camera. Note that generally, the higher the ISO, the more difficult it is to obtain a clear image.
7. While holding the camera very still, a photograph can be taken, and the image can be examined to see if the quality of the image is satisfactory. Excessive blur from camera shake can be minimized: (a) by using a remote control, (b) by attaching the camera to the microscope using sticky tape or bungee cords, or (c) by constructing a frame to hold the camera in place.

Some basic steps can help make sure that the images taken off cameras are of good quality.

Slides should be clean, and one can use Windex glass cleaner or alcoholic wipes to make sure the slides are not dirty or have fingerprints. Using white balance helps make the images look more natural. Currently there is a wide variety of post-capture image editing software that can help enhance the image quality. Adobe Photoshop is one of the most commonly used software and can help edit the images to provide high quality.

23.4.6 Mobile Phone Cameras

Modern smartphones have integrated high-quality cameras, and they have even greater photographic capacity greater than many point-and-shoot cameras; images from slides can be captured either using manual positioning of the mobile phone against the microscope's eyepiece or by using an adapter. Some new smartphones have optical zoom which result in better quality of images when needing to get the subject closer.

The use of smartphones is justified under certain circumstances and has several advantages:

- They are widely available even in remote rural areas.
- Most places have Internet connectivity.
- Photomicrographs are easily taken when needed for sharing interesting cases, rapid consultations, screening selected cases to assess the need for submitting the entire case for consultation or submitting imagines for teleconsultation (telepathology).
- In education settings, medical students using their own smartphones as auxiliary imaging devices spent more time on microscopy teaching sessions, do not get bored, and speak with each other about images. It works as a "toy" that motivates them to discuss the captured images from microscopic slides and positively changes their attitude toward microscopy teaching sessions [13].

The first time a mobile phone camera was used to take a picture of the microscope's field was in 2008, by Bellina [14], with the purpose of confirming a diagnosis of malaria from a blood sample; the images were sent via multimedia messaging service for telediagnosis purposes to a reference center (Fig. 23.8). These images were taken targeting the microscopic field with the camera objective, surrounding the camera with the hands to avoid environment light interference, and slowly moving the camera closer to the microscope until the microscopic field was targeted and in focus. A patent application

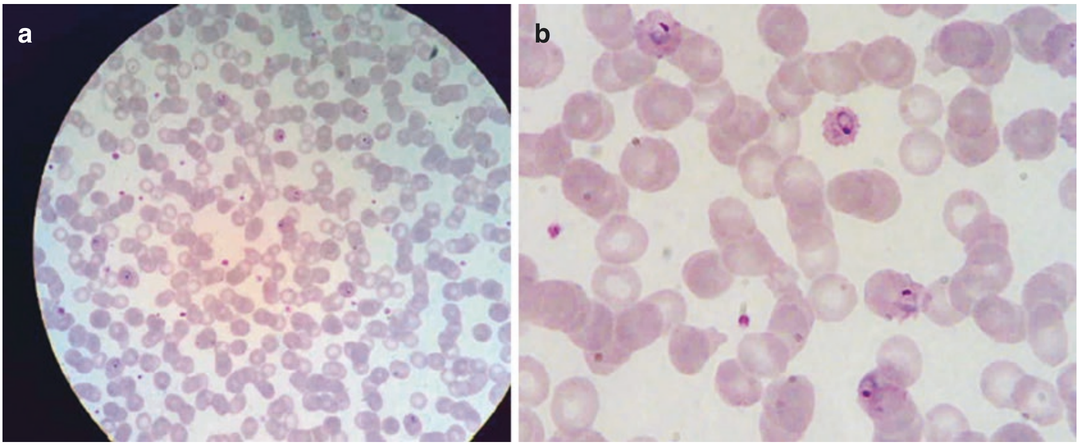

Fig. 23.8 (**a**) Left: *Plasmodium falciparum* rings in erythrocytes, May-Grunwald-Giemsa stain. With mobile phone camera without enlargement. (**b**) Right: *Plasmodium falciparum* rings in erythrocytes, May-Grunwald-Giemsa stain. With mobile phone camera zoom enlargement. (Picture courtesy of Bellina Livia, MD https://liviabellina.wordpress.com/livia-lessons-suggestions-and-didactic-materials/)

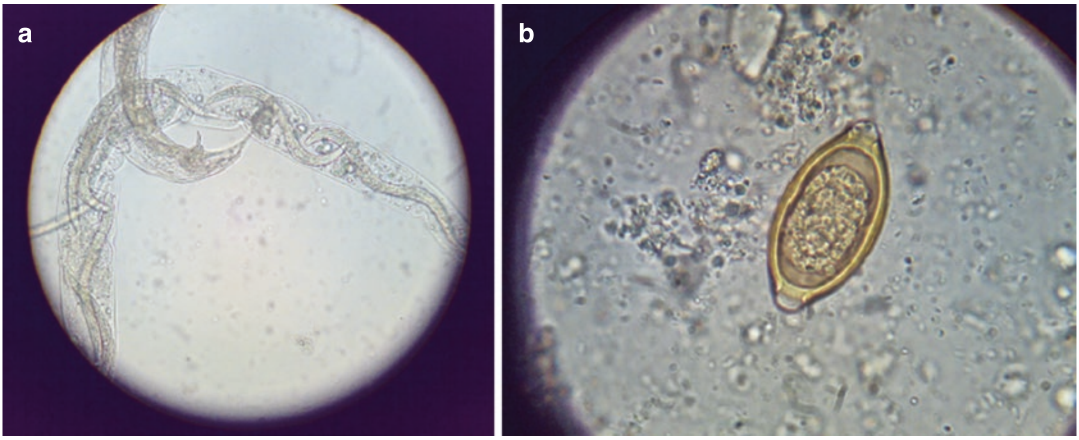

Fig. 23.9 (**a**) Left: *Ancylostoma duodenale*; (**b**) *Trichuris trichiura* egg. (Pictures courtesy of Bellina Livia, MD (https://liviabellina.wordpress.com/livia-lessons-suggestions-and-didactic-materials/))

(EP2116884A1) of this method was fulfilled by Bellina Livia [15] and later published in collaboration with collaboration of Missoni [9]. Using this method, images from a variety of samples and preparations (wet or stained) of biological material (blood, stools, urinary sediment, and histologic) can be used for teaching purposes, telediagnosis, or training local health workers of rural areas (Fig. 23.9). Nowadays, an association called Mobile Diagnosis (MD) (http://www.mobilediagnosis.net/index.php) provides guidance and diagnostic and educational support using mobile phone technology mainly for resource-limited and rural settings [16, 17].

In 2014, Morrison and Gardner [18] published a similar freehand method for capturing photomicrographs using a smartphone that has been dubbed the "Morrison technique" in subsequent publications [1, 19]. This technique is characterized by the use of the last three fingers of the left hand to brace against the left ocular (eyepiece) of the microscope for stabilization, while the smartphone is held between the remaining left fingers (thumb and second finger) and the right hand leaving the right thumb free to focus the camera and capture the image (Fig. 23.10). The smartphone camera is aproximated to the right eyepiece while focusing on the light in the center of the ocular until the image comes into focus. The camera's zoom function can be used for removing vignetting (Figs. 23.11, 23.12, 23.13, and 23.14). Successful smartphone microscopic photography is dependent on the ability to hold the camera steady [10, 18, 19] and the quality of the camera of the phone. Umudum [13] used the Morrison Technique with the "grid" function of the smartphone camera. When bringing the smartphone closer to the ocular lens, the small light coming from the ocular is adjusted in the center of the grid. Other authors have described a similar technique for smartphone photomicrography [20].

Fig. 23.10 Capturing photomicrograph using a smartphone (iPhone 6S). Technique described by Morrison and Gardner. (Pictures from Fernández Katrina, MD)

Numerous adapters have been developed so far to help capture images from devices with oculars,

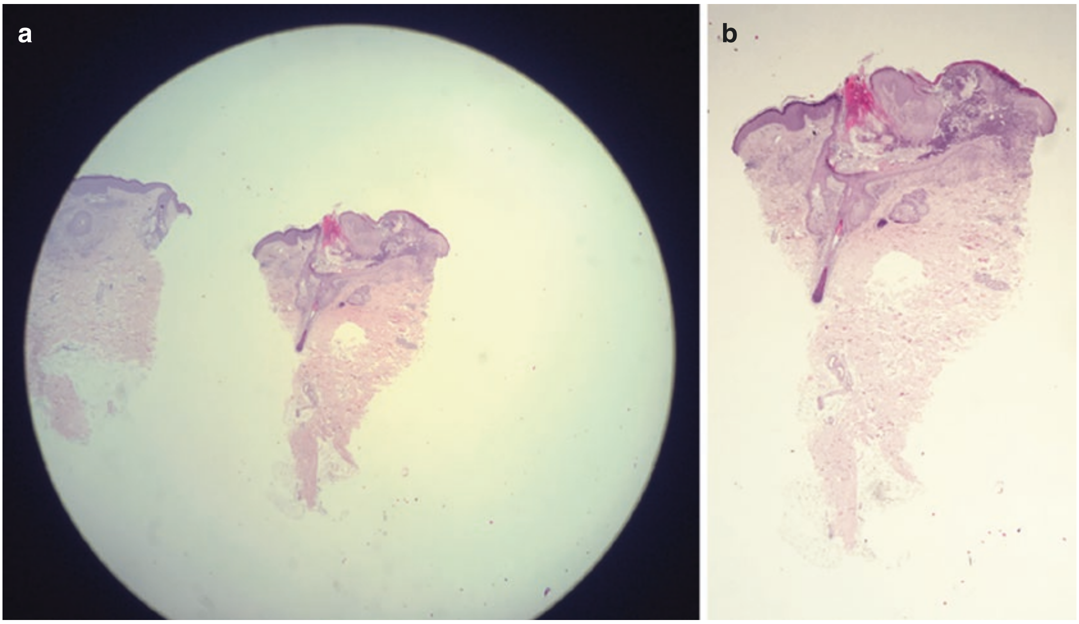

Fig. 23.11 (**a**) Left: hematoxylin and eosin staining of skin biopsy (2×) without enlargement, and (**b**) right: with smartphone (iPhone 6S) camera zoom. Both pictures were made with "grid" function of the camera. (Pictures from Fernández K, MD)

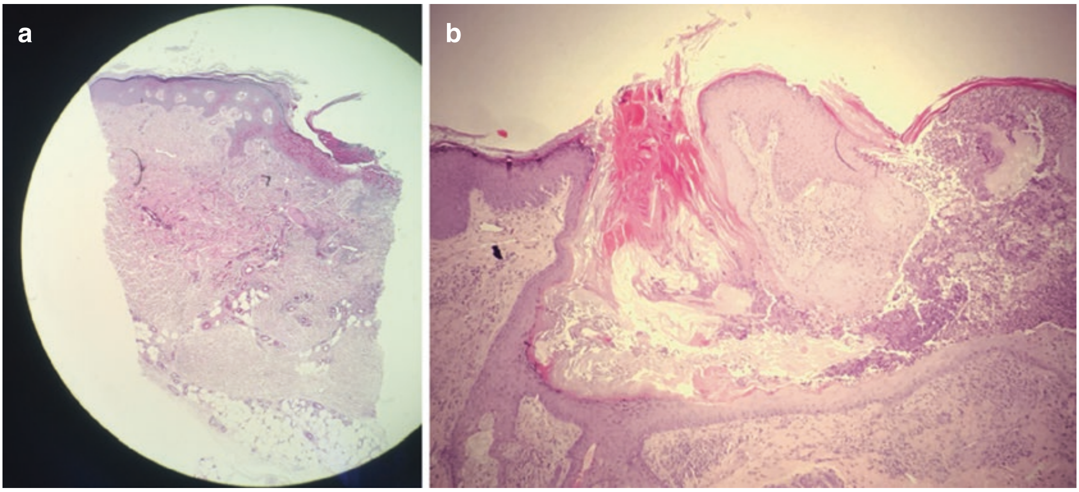

Fig. 23.12 (**a**) Left: hematoxylin and eosin staining of skin biopsy (10×), without enlargement, and (**b**) right: with smartphone (iPhone 6S) camera zoom. Both pictures were made with "grid" function of the camera. (Pictures from Fernández Katrina, MD)

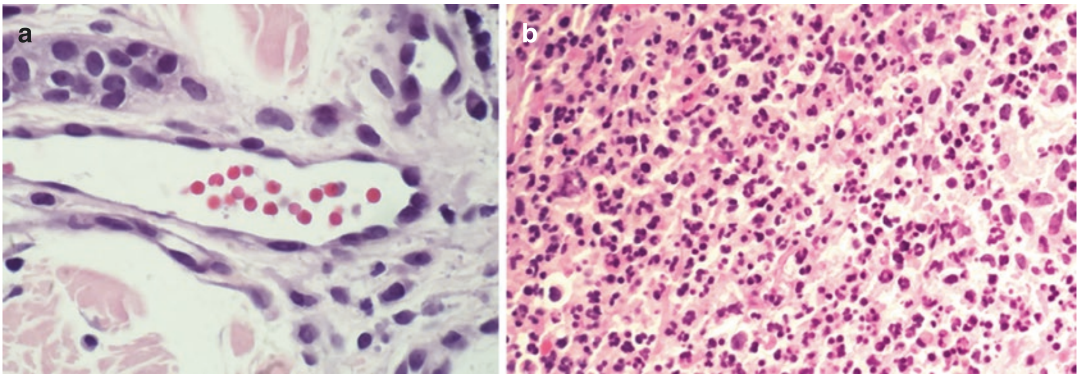

Fig. 23.13 (**a**) Left: hematoxylin and eosin staining of skin biopsy (40×) with smartphone (iPhone 6S) camera zoom avoiding vignetting. (**b**) Right: hematoxylin and eosin staining of skin biopsy (20×) showing diffuse infiltrate mainly composed by neutrophils.Both pictures were made with "grid" function of the camera. (Pictures from Fernández Katrina, MD)

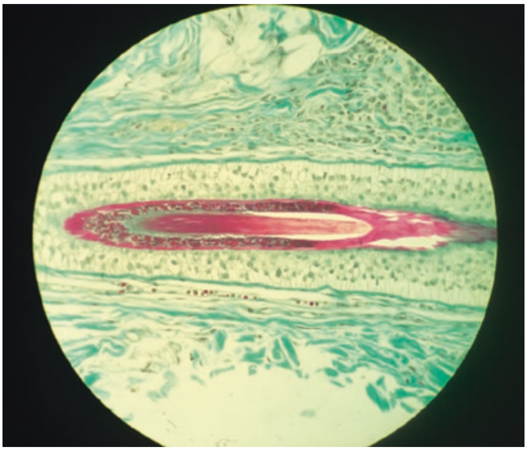

Fig. 23.14 Grocott's methenamine silver stain of skin biopsy (40×) with smartphone (iPhone 6S) camera without enlargement. Picture was made with "grid" function of the camera. (Pictures from Fernández Katrina, MD)

especially microscopes, but it goes beyond the scope of this chapter to describe each of them. There are also reports of adapters developed from soft drink aluminum [21], cardboard [21], hardboard [22], or PVC piece of pipe [23].

Roy et al. [7] published a report that compared three commercial smartphone adaptors for microscopic image capture in the clinical setting:

- *Skylight adaptor* (Skylight Healthcare Systems, Oakland, CA) can be used with nearly all smartphones and consist of two components: a platform—which holds the smartphone and allows movement to align the phone camera to the eyepiece—and the eyepiece adaptor which requires minimal movement to optimize the desired focal length (Fig. 23.15).
- *Magnifi adaptor* (Arcturus Labs, LLC, Palo Alto, CA) is specifically designed for iPhones and consists of two components: an iPhone polycarbonate plastic case which fits the phone using stainless steel bands and a removable microscope eyepiece adapter. The adapter fits the case using Magnifi's unique Bayonet mount. The Magnifi comes with flexible

Fig. 23.15 *Skylight adaptor* (Skylight Healthcare Systems, Oakland, CA). (Available from: https://www.kickstarter.com/projects/190596902/the-skylight-a-smartphone-to-microscope-adapter?ref=email)

Fig. 23.16 *Magnifi adaptor* (Arcturus Labs, LLC, Palo Alto, CA). (Available from: https://www.arcturuslabs.com/)

rubber rings for the range of eyepiece diameters (25–38 mm) (https://www.arcturuslabs.com) (Fig. 23.16).

- *Snapzoom adaptor* (HI Resolution Enterprises, Honolulu, HI) is designed to fit a variety of smartphones with or without cases with up to 3.5 in. in width. It is suited for larger phones and still compatible with many of the small ones (smartphones of up to 3.67 in. (93 mm) wide and 0.79 in. (23 mm) thick—with or without a case.) They are suited for compact binoculars and smaller microscope eyepieces. Eyepiece jaw accepts any eyepiece with an outside diameter between 0.91 and 2.17 in. (23–55 mm) wide and a minimum 1 in. (25 mm) in height.
- This adaptor consists of two connected parts: a stage or platform, for holding the phone allowing movement and aligning the phone's camera to the eyepiece, and a binocular eyepiece adaptor (http://snapzooms.com/) (Fig. 23.17).

Several factors contribute to image quality in the setting of using mobile phone adaptors and depend of the model of smartphone being used. Resolution depends on the microscope's optics. These are:

- Proper alignment of the camera lens and ocular lens
- Resolution of the image

Fig. 23.17 *Snapzoom adaptor* (HI Resolution Enterprises, Honolulu, HI). (Available from: http://snapzooms.com/)

- Focal length of the camera on the smartphone
- Specific smartphone settings (such as shutter speed and autofocus/autoadjust settings)

There are some disadvantages of using these adapters: (1) mobile phone protective cases are more difficult to adjust to this adapters; (2) mounting and dismounting the adapters from microscope to switch between photographing and simply viewing are time-consuming; some adapters needed to be readjusted with each reattachment; and (3) there is a fixed distance to the ocular lens that cannot be overcome when in need to place the camera closer to the ocular.

Panoramic images can be taken of microscope slides. They are known as "virtual microscopy" because the viewing experience is analogous to using microscope in real time. A smartphone adapter can be used in conjunction with the panorama function of the phone for capturing this "whole slide" image.

With the advent of pathology scanners and viewing whole slide images (WSI) on computer screens or high-resolution LCDs, capturing high-resolution images has become relatively easy in current times. Inbuilt software programs on the viewers allow easy downloading of screenshots either as png or jpeg images. However this is still only available in developed countries as scanning equipment and software are relatively expensive and only possible in large academic centers.

23.5 Photographing Other Procedures

Smartphone technology extends beyond the pathology field as it can be used for capturing bright field digital color images of malaria parasites in thin and thick blood smears, sickled red blood cells in peripheral blood smears, and—using fluorescence—tuberculosis bacilli in Auramine O-stained sputum smears [24]. Maude et al. [8] described compact camera microphotography technique and applied their technique to smartphone microphotographs of a ring form of *Plasmodium falciparum* in peripheral blood, *Ascaris lumbricoides* and *Trichuris trichiura* ovum.

Dermatologist frequently uses microscopes to aid in the identification of common disorders like scabies, demodicidosis, leishmaniasis, blistering diseases, viral and bacterial infections, and also exfoliative cytology of keratinocytic tumors. In this settings adjusting compact cameras or smartphone cameras to photographs findings under microscope [25] will be of great help in documenting, showing the patient or for educational purposes.

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24

Photography in Digestive Endoscopy

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and Reza Gholami

Contents

24.1 Introduction

The aim of photography in digestive endoscopy is to obtain adequate, relevant, and quality endoscopy pictures in order to record therapeutic findings and evidence for a possible diagnosis. Video recording would complete the documentation, but such files take up a large amount of space on any filing system.

Photo documentation is mandatory for the following purposes:

- To provide a complete case record for each individual patient
- As a quality measure, with specific requirements clearly described (e.g., anatomical landmarks) [1, 2]
- To facilitate communication between physicians, patients, healthcare providers, and second-opinion advice
- As a useful teaching resource
- As supporting evidence, which in some cases could protect physician in medicolegal matters

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Achieving clear and adequate photo documentation requires skill. In Japan, photography is included in the endoscopy curriculum, where trainees are required to take multiple pictures (up to 50) in order to prove the completeness of each of their endoscopy examinations.

This aim of this paper is to provide an overview of photography in gastrointestinal (GI) endoscopy. We summarize the very earliest developments in both optical technology and endoscopic examination and discover how progress in visual and photographic devices has enabled advancement in diagnostic and therapeutic endoscopy.

24.2 Gastrointestinal Endoscopy

Endoscopy is a procedure that allows the inspection of internal hollow organs (from the Greek “endo” meaning within and “skopein” to view or observe). GI endoscopy is the examination of the GI tract, which is performed for diagnostic and therapeutic purposes.

GI endoscopy is performed through the natural orifices (mouth or anal canal) using special hollow tubes called endoscopes, which enable access to the GI tract from outside the body. The endoscope shaft contains separate channels for various functions: the optical component transfers light through optical fibers and receives images of the digestive lumen; an air–water system can be used to inflate the digestive tract and clean the lens if necessary; the biopsy/operative channel allows specimens to be taken or treatments, such as polypectomy, removal of biliary stones, or stenting, to be performed. Nowadays, physicians and nurses work in front of high definition screens.

The field of GI endoscopy has known continuous development, especially in image quality and processing. Most of the images obtained in current practice are digital, making them readily accessible and providing huge benefits for physicians, patients, instructors, and researchers.

24.3 Historical Background

24.3.1 Endoscopy

It is possible that the practice of gastric intubation for therapeutic procedures, such as gastric emptying using hollow canes, rods, or tubes, might be older than Christianity [3]. The earliest known attempts to look inside the living human body through the natural orifices date back to around 400 years BC, when Hippocrates in Greece used the rectal speculum to look inside the anal canal [4]. The term “endoscopein” is originally attributed to the Persian father of early modern medicine Avicenna (980–1037 AD), although it was Albulassim (912–1013 AD), an Arabian physician, who first used reflected light from a mirror as a source of illumination when performing an endoscopic examination of the exposed vagina [5, 6].

The first useful endoscopic instrument that allowed inspection of natural body orifices using a light source other than the sun was made by Bozzini in 1806. Bozzini invented the “Lichtleiter” or “the Light conductor,” which consisted of a metal tube and a mirror that reflected candlelight into the body cavities through the tube [7].

Several attempts were subsequently made to develop this technique using the same concept—hollow tubes/funnels and light sources for illumination—resulting in the appearance of other primitive versions of the endoscope, such as the instruments developed by Segalas (1826), Fisher (1827), Bonnafont (1834), Avery (1843), and Désormeaux (1853) [8].

In 1868, Kussmaul performed esophagoscopy with a straight, rigid, metal tube over a flexible obturator and was able to diagnose an esophageal carcinoma. He went on to perform the first gastroscopy but was only able to see bubbles and mucus [9, 10].

The next major innovation came with the German urologist Nitze (1848–1906) who, together with well-known instrument maker Leiter (1830–1892), developed the Nitze–Leiter cystoscope in 1879 [11].

The greatest challenge facing developers of endoscopic instruments was illumination. The invention of the incandescent light bulb in 1880 by Thomas Edison (1847–1931) was a step forward in this regard. However, heat and the risk of thermal injury was a big limitation of the new bulb [12]. Subsequent development of the bulb overcame the problem of thermal risk, giving rise to the "cold" Mignon lamp, a small vacuum lamp that could be inserted at the end of a cystoscope and placed inside the bladder.

In 1881, the era of flexible endoscopy began with the work of Mikulicz (1850–1905) who developed an instrument that could be bent by 30° in its distal third [13].

Another development was the use of an external light source transmitted through fiber bundles. In 1959, Hopkins (1918–1994), a physics professor at the University of Reading, UK, invented the rod-lens system. The first flexible fiber ureteroscope using these principles was introduced in 1960 by American Cystoscope Makers, Inc. (ACMI) [14] (Figs. 24.1 and 24.2).

In GI endoscopy, the first routine clinical use of photography was with the gastrocamera, which was developed following collaboration between Japanese endoscopists and Olympus Optical Co. Ltd. The gastrocamera blindly took pictures of the gastric cavity for the detection of gastric cancer. In the early 1960s, Basil Hirschowitz together with ACMI in the USA developed the first flexible fiberscope, which could view the esophagus and allowed insufflation, suction, and two-way control [15]. This was closely followed by developments from Japanese physicians in collaboration with Machida Endoscope Co., Ltd.

Further developments extended both the diagnostic and therapeutic capabilities of the endoscope: the scope became longer, making access to the duodenum possible; greater flexibility with tip deflection up to 180° allowed retroflexion; and the scope became equipped with channels for suction, air/water infusions, and instrument insertion, allowing lesion diagnosis or treatment.

A more important development was achieved in the late 1960s with the invention of the duodenoscope, which was a side-viewing endoscope rather than the conventional axial-viewing instrument. The new duodenoscope incorporated a laterally placed lens at the end of the scope, allowing visualization of the duodenal papilla and cannulation with the help of an instrument elevator lever. The introduction of the duodenoscope resulted in the development of the endoscopic retrograde cholangiography procedure, which is used for the diagnosis and treatment of biliary tree and pancreatic duct diseases. The first exami-

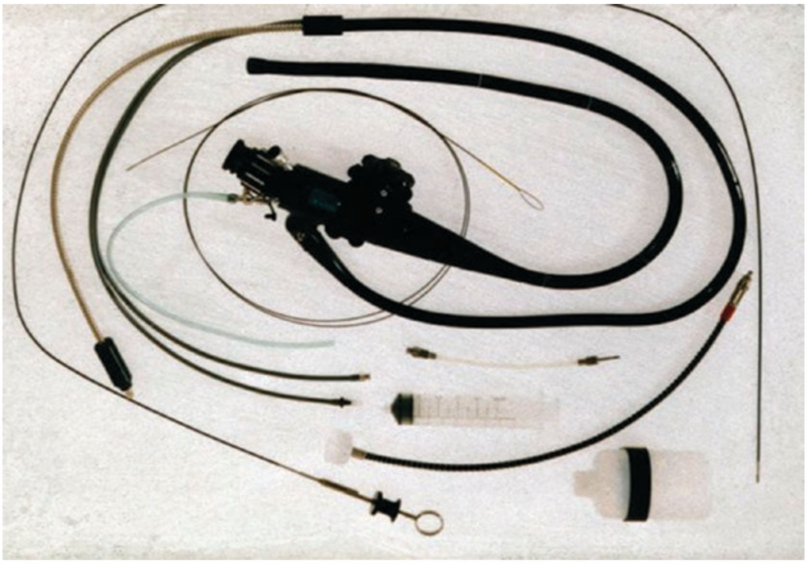

Fig. 24.1 ACMI 70 s colonoscope

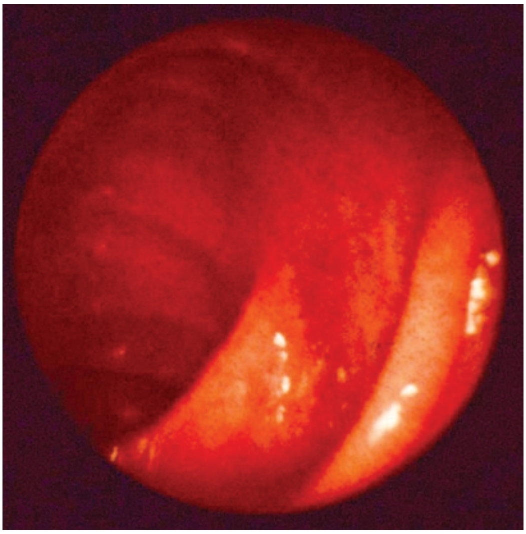

Fig. 24.2 ACMI fiber gastroscope image

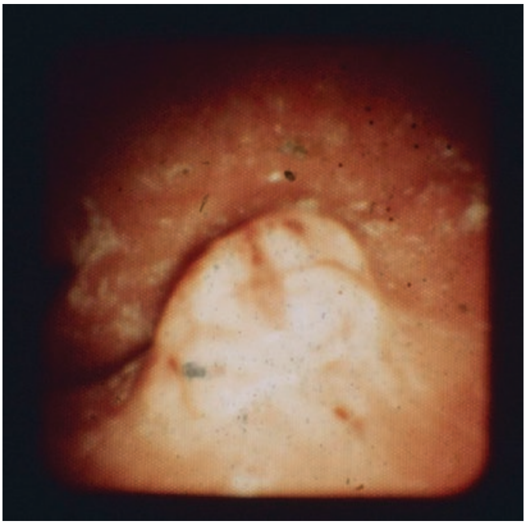

Fig. 24.3 Olympus fiber gastroscope (1974)

nations using the duodenoscope were by McCune in the USA and Oi in Japan [16, 17].

At the same time, endoscopes for colonic examination were developed, and the first colonoscopies were performed by Shinya and Wolff in 1969 [18].

The major limitation of the fiberscope was the quality and resolution of the pictures. Japanese manufacturers rapidly became world leaders in high quality fiber optic technology. However, the fibers were, at this time, very fragile, and image quality was impaired by black spots (Fig. 24.3).

24.3.2 Photography in Endoscopy

The first camera described in history was the camera obscura (from the Latin, meaning “dark room”: camera “chamber or room” and obscura “dark”). The earliest known written record of the camera obscura can be found in Chinese writings dating back to the fourth century BC [19].

The first successful preserved image taken by a camera was made in 1816 by Nicéphore Niépce using a piece of paper coated with silver chloride as a film [20, 21].

In digestive endoscopy, the first limited description of the esophageal lumen was achieved using rigid endoscopy. However, for many years, visual representation of endoscopic findings and anomalies was the work of artists, who drew schematic representations of the images based on a description of what the physician had seen. This all changed with the introduction of the camera.

Photographic images were first used in routine clinical practice in 1950 when Uji et al. developed the gastrocamera in collaboration with Olympus. The gastrocamera consisted of a camera unit (lens, flashlight, and pre-packed film roll) mounted onto the distal end of a flexible tube and a control box with an exposure switch at the upper end [22]. The camera took a limited number of pictures from different levels and at different degrees of rotation to ensure as complete coverage of the stomach as possible. However, the operator could only inspect the patient’s stomach after the film had been processed. Nevertheless, the device was deemed an important development in Japan, where gastric cancer is a national healthcare priority.

The subsequent development of the fiberscope allowed direct transmission of images and simultaneous visualization by the examining physician; through an eyepiece placed at the external end of the endoscope, physicians could view a magnified (×15) image. The gastrocamera itself became rapidly obsolete, as improvements in the optical system of the gastroscope combined with the introduction of fiber optics. By attaching a small external camera (first the Olympus Pen F and then the famous OM system) to the eyepiece of the gastroscope and employing optical fibers for the transmission of images, real-time endoscopic photography was finally made possible.

Despite this important advance, one of the limitations of the camera system was the weight that it added to the endoscope, restricting the operator's movements and affecting the quality of the examination. Recording the examination was also a real challenge for the same reason, as movie cameras were very heavy and cumbersome for clinical endoscopic examinations. Consequently, still images were mainly used in scientific publications, lectures, and teaching.

The next and probably most important breakthrough for endoscopy and endoscopic photography was the invention of the photosensitive charge-coupled device (CCD) in 1969 at AT&T Bell Labs [22, 23]. CCD is a chip of light-sensitive elements called pixels. The device converts conveyed optical photonic images into electric signals for display on a television monitor. The quality, or resolution, of the images is directly related to the number and density of chip pixels. Early CCDs were too large for small-diameter gastroscopes, so the first CCD-based commercial video image endoscope, the Video Endoscope, was a colonoscope produced in the USA by Welch Allyn in 1983 [24]. This was soon followed in Japan by Olympus, Fujinon, and Pentax, whose respective commercial successes were linked to the mechanical possibilities of their endoscopes. As ACMI in early 1980s, Weich Allyn in late 1980s, American pioneers at their stage disappear.

CCD detects photons and light intensity (brightness) by means of the accumulated electric charge, which is proportional to the perceived light intensity; therefore, CCD can only produce black and white images and not color. Two methods were available to generate colored images. The first method was the sequential system, which is based on the analysis of light reflected by tissue that is successively illuminated with the three primary colors of white light: red, green, and blue (RGB). The sequential imaging technique uses a monochrome rotating color filter wheel in front of the light source at a rate of 30–50 times per second. Then, the CCD detects reflected RGB light, and the resulting signals generated are processed into a digital code. Decoding this signal via an inverse operation generates a video-television image. Because the RGB filter spins at speed, it takes a certain amount of time to capture all three-color components in an image. If the endoscopic lens moves during this time, different images/colors can overlap on the CCD, causing a distracting flickering signal with colored image separation, especially during endoscope tip motion; this was one of the limitations of this system (Fig. 24.6).

The second method used a mosaic filter between the lens and the CCD to form the so-called color CCD chip. In this technique, each pixel of the chip is covered by a mosaic filter that is transparent to one of the primary colors or their complements (cyan, magenta, or yellow) and detects only reflected light of the same wavelength to finally form, after processing, a colored image. The major advantage of this technique is the short exposure time required to accumulate all three colors, rendering moving images smooth and more natural.

In the early 1990s, an American image sensor device physicist and engineer called Fossum invented the complementary metal oxide semiconductor (CMOS) device [25]. The CMOS chip, an alternative to the CCD, offered reduction in both cost and device size, and so it was more suitable than CCDs for mass production, with lower energy consumption and less heat production. However, the advantages of CMOS chips came at the expense of image quality, and so CMOS cameras still generally required companion chips to optimize image quality, which increased cost and power consumption [26, 27].

The advantage of video endoscopy was huge: the endoscopist was able to gain binocular vision in a comfortable position, holding the endoscope at chest level at a safe distance from the patient, instead of bending forward and looking into the endoscope through a single eyepiece. The improvements allowed the endoscopist freedom of movement and facilitated endoscopic maneuvers, which were especially important for therapeutic procedures. Video endoscopy also allowed several monitors to be employed, giving visual access to assistants, technicians, and other medical personnel and resulting in better communication, coordination, and safety when performing more complex endoscopic procedures. The digitalization of the image using digital processors and computer systems allowed image storage, retrieval, and transfer, as well as image processing and analysis using complex information technology algorithms for diagnostic purposes, and so many benefits for other activities such as teaching, documentation, and research (Figs. 24.7 and 24.8).

Later on, research and development were focused on image capture and analysis, as the need to obtain photographs of the GI tract became increasingly important for complete endoscopic assessment in order to develop classifications with clinical outcomes. For example, colonic polyps are assessed during colonoscopy using the narrow-band imaging international colorectal endoscopic (NICE) classification: hyperplastic polyps (not removed), adenomatous lesions with limited invasion (removed by endoscopy), or invasive polyps (require surgery). This NICE classification was only possible thanks to thousands of pictures taken in Japan, Europe, and the USA (Fig. 24.9).

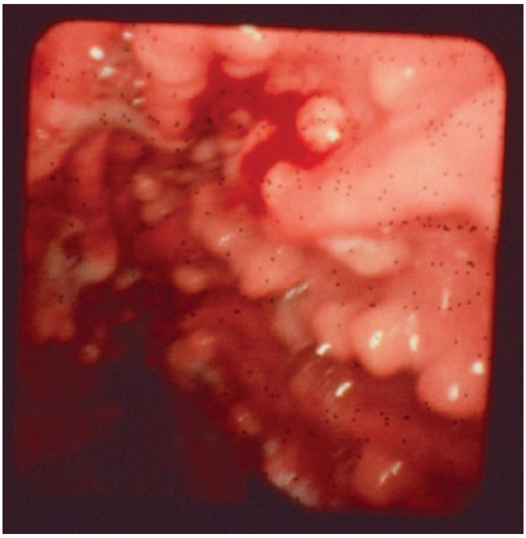

Fig. 24.4 Olympus fiberscope (1980)

24.4 Advanced Endoscopic Imaging

To enhance the diagnostic objective of GI endoscopy, several techniques were developed to increase the resolution and contrast of the endoscopic image to make it easier for the human eye to detect lesions and even to predict their histology as normal, dysplastic, precancerous, or

Fig. 24.5 Olympus fiber-colonoscope (1985)

Fig. 24.6 First Olympus electronic video endoscope (1986)

Fig. 24.7 High definition endoscope: stomach aspect

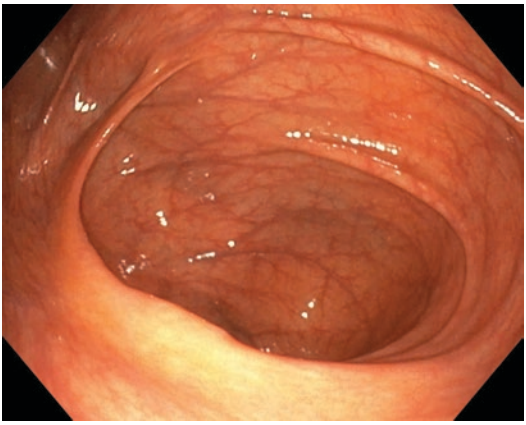

Fig. 24.8 High definition endoscope: ileo-caecal landmark

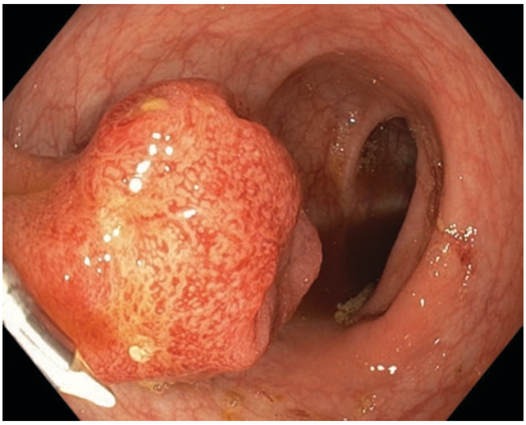

Fig. 24.9 Colonic polyp with high definition

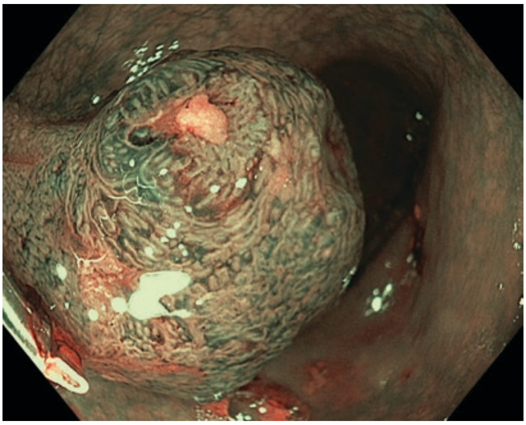

Fig. 24.10 Same polyp with NBI illumination: the superficial mucosal aspect and microvessels are more visible and used for classification

cancerous [28]. In the 1970s, Japanese investigators used dye spraying, such as with indigo carmine, methylene blue, or Lugol's iodine dyes, to stain the mucosa during endoscopy, a technique called chromoendoscopy [29]. This technique was time-consuming and therefore not adopted for routine use [30], especially when Japanese researchers linked chromoendoscopy to optical magnification (×80), which, though impressive, was cumbersome to use.

The concept of predicting histology was made simple and easily available with the development of the so-called virtual chromoendoscopy with high-resolution endoscopes. High-resolution endoscopic imaging incorporates multiple factors (Table 24.1), including sensor definition, optical aspects, and electronic elements, and the overall image quality relies on optimization of all constituent parts. As in digital photography, it is possible to modify color reproduction or apply contrast enhancement. The final result, as in traditional photography, relies on field of view and depth of field (2–100 mm). Illumination is particularly critical, with over- or under-illumination dependent on the distance between the endoscope light and the digestive wall. Optical magnification is only achieved by narrowing the depth of field, and this is another challenge in the quest for high quality pictures.

The narrow-band imaging (NBI) technique involves using a narrower spectrum of light than normal white light, a spectral bandwidth that mainly corresponds to blue light. This is achieved by applying special optical filters or by digital filtering (Fig. 24.11). Most manufacturers of endoscopic instruments offer similar functionality using their own built-in systems, hardware or software (Figs. 24.9 and 24.10).

Enhanced endoscopy imaging is the latest development in digital endoscopy for routine clinical practice. Selected filters with narrow bandwidth allow visualization of specific features of the GI tract mucosal layers, allowing not only detection of lesions but simultaneously facilitating classification and assessment of depth of invasion in case of carcinoma; for example, red filters are used to detect large vessels in the digestive wall.

For all imaging developments, adequate still pictures are mandatory and therefore require the endoscopist to become a good photographer (Fig. 24.11).

Table 24.1 Factors involved in high-resolution endoscopic imaging

Factors influencing image quality
1. Resolution
2. Magnification power
3. Contrast
4. Angle of field
5. Depth of field
6. Evenness of illumination
7. Automatic brightness control
8. Signal noise
9. Color accuracy and color tone
10. Dynamic range
11. Gamma

24.4.1 Small Bowel Endoscopy

For many years, conventional endoscopy was limited to the upper part of the jejunum using push enteroscopy and the terminal ileum from the anal approach using colonoscopy. Therefore, examination of the small bowel was largely left behind, as flexible endoscopes struggled to advance through the entire length of the small bowel (about 7 m). Then, a team of scientists from Israel and the UK invented a miniature cam-

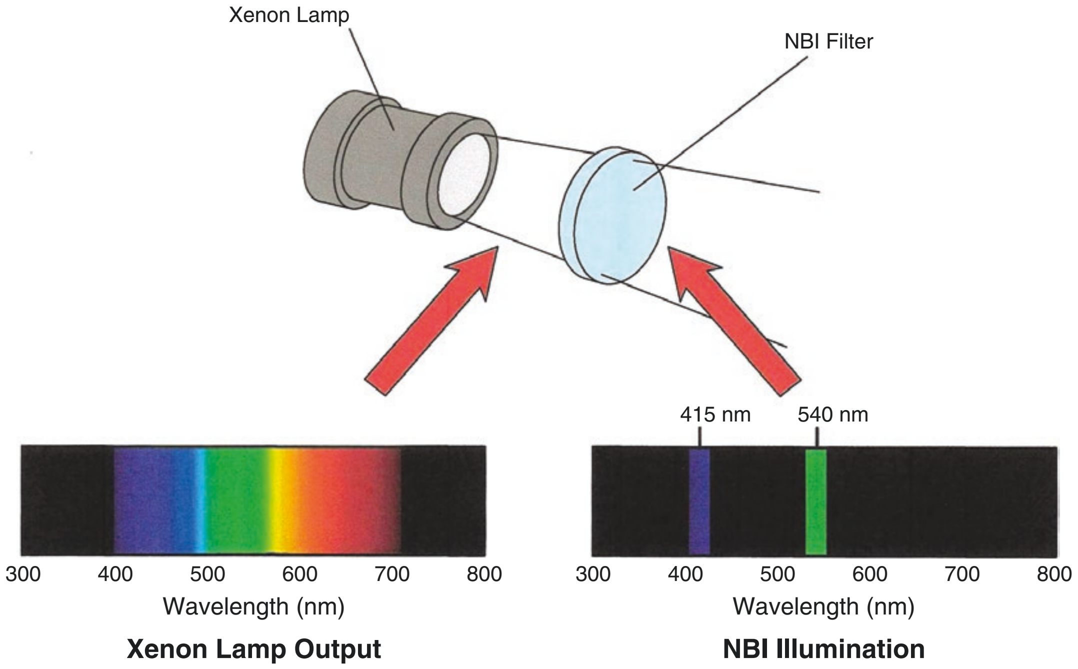

Fig. 24.11 NBI illuminating system

era in the form of a capsule, and wireless video capsule endoscopy (VCE) was born. The capsule consisted of a lens, a CCD image sensor, light-emitting diodes for illumination, the hardware to wirelessly transmit the images to an external receiver, and a battery to power the device. An antenna-equipped device located over the abdomen of the patient received and recorded the images in another special device, and images were analyzed using dedicated computer programs. In October 1999, P. Swain from the Royal London Hospital was the first human to swallow a VCE device [31]. VCE has since become a vital technique for inspection of the small bowel for multiple indications. In particular, VCE is the gold standard noninvasive method for small bowel diagnosis especially in the case of obscure GI bleeding. Although VCE continues to evolve, with multiple new features and designs, even the latest technical improvement cannot match the resolution of traditional endoscopes. Another limitation is the reading time, with 12 h of video recording at 4–8 pictures per second. In order to the reduce reading time, a mathematical algorithm is applied, which isolates and compresses pictures that are similar in order to more easily track the changing mucosa and detect any abnormalities.

Meanwhile in Japan, H. Yamamoto in conjunction with Fujifilm developed electronic video enteroscopy based on the balloon technique. Although this technique was time-consuming and cumbersome, it made total endoscopic examination of the small bowel possible. Double-balloon, single-balloon, and spiral enteroscopes are mainly used for therapeutic purposes.

24.4.2 Endoscopic Ultrasound

Endoscopic ultrasound (EUS) or echoendoscopy was developed by Olympus in the late 1970s and 1980s and is a medical procedure in which an ultrasound probe is coupled to an endoscope in order to obtain images. The technology is used for diagnostic imaging of the internal organs located around the GI tract in the chest, abdomen, and colon. Examination includes the walls of the digestive tract, where any invasion of polyps or tumors can be detected, allowing appropriate therapeutic decisions to be made [32]. Combined with Doppler imaging, nearby blood vessels can also be evaluated. Photography relies mainly on high-resolution pictures that are totally different from those of conventional endoscopy. A similar technique called endobronchial ultrasound (EBUS) is performed by pulmonologists to examine the respiratory system and surrounding structures, as well as to perform transbronchial needle aspiration or other diagnostic or therapeutic procedures using EBUS guidance.

24.5 Criteria for Good Endoscopic Imaging and Documentation

Endoscopic photography is now considered an important element of medical documentation for hospitalized and non-hospitalized patients. As a result, criteria for good endoscopic imaging have been established for quality control purposes and to standardize this type of documentation. Photography is certainly a skill to be acquired and developed, and because not all endoscopist are good photographers or at least do not have equal skill, recommendations have been made to ensure that the objectives of endoscopic photography are met and that quality images are obtained.

Before the endoscopic procedure is started, measures should be taken to ensure the highest quality of images by considering the hardware capability and by eliminating external limiting factors.

1. Careful treatment of the endoscopic hardware, from cleaning to storage, should be observed. Proper use of the instruments and application of the highest quality indicators of good endoscopy unit functioning is mandatory for optimal results [33].
2. The lens of the scope should be clean. The lens should be checked prior to starting the examination with a soft tissue. During examination a waterjet in built in the equipment and active by the physician.

3. Patients should be adequately prepared, especially for colonoscopy where any residue could limit the diagnostic ability and quality of the images.
4. Adequate insufflation should be utilized to ensure maximal exposure of the organ under examination.
5. Visibility may be increased by removing any debris that might obscure the view, for example, by aspirating fluids, cleaning tissues using the water pump, or cleaning the lens by rinsing with water and using air insufflation pressure. Bubbles can be eliminated by rinsing with water rather than using aspiration or by using defoaming agents such as simethicone, which act by reducing the surface tension of small air bubbles to form larger ones before they disappear.
6. Light intensity can be adjusted by the video processor. If necessary, manual adjustment can be made to ensure uniform illumination and avoid glare that could also reduce the quality of the picture.
7. The use of medications that reduce intestinal motility could be useful. Glucagon, for example, administered intravenously or intramuscularly, has a relaxing effect on the smooth muscle and thus GI motility.
8. Proper sedation is needed to avoid pain resulting from air insufflation and to limit patient movement, which could reduce the quality of the procedure and thus also the images obtained.
9. Some endoscopes are equipped with a zoom function. Magnification power (×80) allows close-up images, but the picture quality is impaired by a very narrow depth of field.
10. Endoscopist should take their time, use the freeze function, and ensure that the picture is satisfactory, clear, and not hazy before storing and printing.

Nowadays, the full endoscopic procedure can be recorded with still pictures or/and video recording. Data are stored on DVDs or direct electronic files, but this type of documentation is not widely available and not frequently used for many reasons, such as the need for huge memory storage and the time-consuming process of reviewing video files. Thus, photographic documentation remains the most routinely used tool because of its simplicity.

24.5.1 Deciding What to Photograph

The endoscopic examination should be documented in a specified way to ensure that all examined organ tissues have been clearly visualized, including the difficult-to-reach parts that can contain anomalies and can be easily missed. These anatomical landmarks are defined in published recommendations and guidelines to ensure that the examination is well conducted and complete photo documentation of the procedure is available.

The European Society of Gastrointestinal Endoscopy (ESGE) was the first society to publish guidelines for image documentation in endoscopy in 2001 [1].

24.5.1.1 Upper Endoscopy

For upper endoscopy or esophagogastroduodenoscopy, the guideline defines ten locations or landmarks that should be photographed and included in the endoscopy report (Fig. 24.12):

1. Proximal esophagus
2. Distal esophagus
3. Z-line and diaphragm indentation
4. Cardia and fundus in retroflexed view
5. Gastric body (including lesser curvature)
6. Gastric body in retroflexed view
7. Angulus in partial inversion
8. Antrum
9. Duodenal bulb
10. Second part of the duodenum, including the ampulla

24.5.1.2 Colonoscopy

The ESGE has also defined nine landmarks or locations to document on a colonoscopy report (Fig. 24.13).

1. Lower part of the rectum in retroflexed view
2. Lower part of the rectum (taken 2 cm above the anal line)

3. Middle part of the sigmoid
4. Descending colon immediately distal to the splenic flexure
5. Transverse colon immediately proximal to the splenic flexure
6. Transverse colon immediately distal to the hepatic flexure
7. Ascending colon immediately proximal to the hepatic flexure
8. Cecum and ileocecal valve
9. Cecum and appendiceal orifice

Of course, these landmarks are minimal requirements, and any lesions that are detected also need to be documented with still pictures and sometimes video recording. This guideline also forms part of quality assurance, as documentation of these landmarks proves the completeness of the examination. This latter point is particularly important when total colonoscopy is indicated.

24.6 Photographic Classifications: NBI Classification

With high-resolution endoscopes and using NBI, various classifications have been achieved. The most well-known is NICE (narrow-band imaging classification for endoscopy); during endoscopic examination, the physician during colonoscopy detects a polyp (malignant or benign) and is able to differentiate immediately various stages and decide an endoscopic or surgical treatment (Figs. 24.9 and 24.10).

24.7 Image Processing and Storage

As endoscopic imaging provides valuable material for medical records, efforts should be made to organize and save this material in a format and within a system that can be easily reviewed and accessed at any time and by any authorized personnel. The image quality should be maintained, and the system should allow copy and transfer when needed, such as on patient demand or for research purposes.

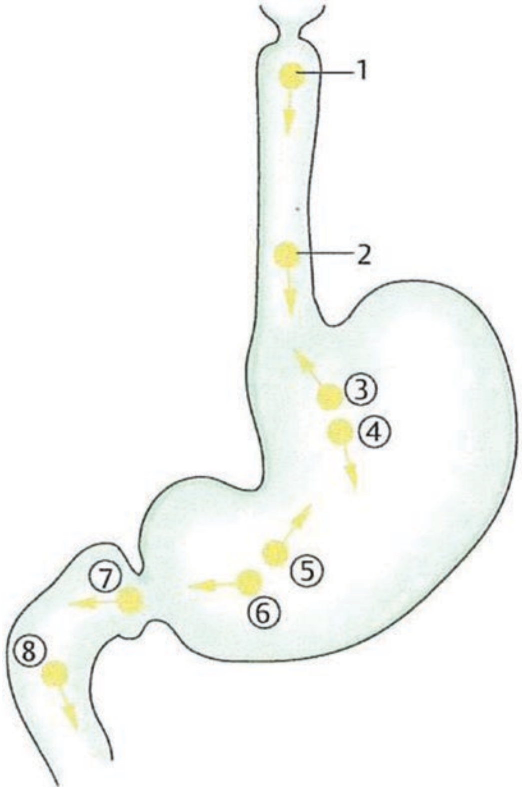

Fig. 24.12 Upper gastrointestinal landmarks

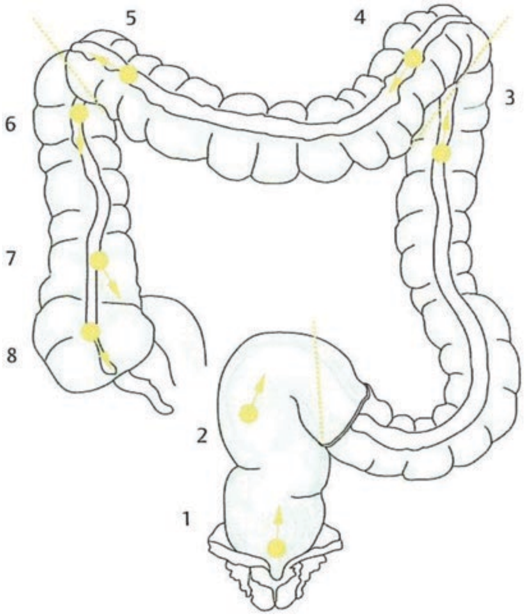

Fig. 24.13 Colonoscopic landmarks

In 2016, the ESGE published a list of requirements to ensure quality improvement for reporting systems in GI endoscopy. The ESGE suggest that endoscopy reporting systems should be electronic, integrated into hospitals' patient record systems, and include patient identifiers to enable automatic links with other data sources. Endoscopy reporting systems should also involve structured data entry, restricting the use of free text entry to a minimum. Separate entry of data for quality or research purposes is discouraged, as is double entry of data by the endoscopist or associated personnel. Systems should facilitate automatic transfer of data for quality and research purposes [34, 35].

Endoscopy reporting systems should also facilitate the inclusion of information on the histopathology of detected lesions, patient satisfaction, adverse events, and surveillance recommendations. The systems should also allow easy data retrieval at any time in a universally compatible format. Finally, any changes in indicators or data entry fields required by professional organizations should be accommodated within the reporting systems [36].

24.7.1 Patient Confidentiality

As with all medical data, it is important to maintain patient confidentiality. In all video endoscopic examinations, the patient's name, examination date, and hospital ID number are recorded, as these details are important to include in medical records in order to avoid mistakes. For scientific use of patient data, however, the name has to be deleted. This could be done immediately after the start of the examination by erasing the patient's name from the film or during the postprocessing of pictures. Deletion of the patient's name is particularly important when pictures are used as part of clinical trials and are exported to other hospital or research centers.

24.8 The Future of Photography in Endoscopy

The most recent development in endoscopic photography is the use of thousands of endoscopic images and powerful computer systems to design artificial intelligence systems to assist endoscopists in their examinations and diagnoses. In addition to lesion detection, computers are also being used for automatic classification, leading to more accurate and faster assessment and avoiding the need for repeat procedures. In the same session, the physician is able to detect a lesion, assess it with high accuracy, and, when necessary, perform therapeutic procedures to treat the lesion.

24.9 Clinical Outcomes

As endoscopy reports existed originally only as a written description, lesions remained somewhat obscure and were only seen by the endoscopist. The use of specific endoscopic recording software, such as the Minimal Standard Terminology developed by the World Endoscopy Organization, American Society for Gastrointestinal Endoscopy, and the ESGE [34], has gone some way to standardize the terminology and descriptions used. But, it was the introduction of endoscopic photography that enabled an important leap in digestive endoscopy: other physicians involved in the patient's care could consult the medical documentation to review what the endoscopist observed; multidisciplinary discussions of mortality and morbidity could be more informed; medical research could be enhanced; and comprehensive supporting evidence could be provided for medicolegal matters. From a scientific point of view, endoscopic pictures are mandatory for elaboration of endoscopic medical classifications using both pictures and characterization of their contents in order to reach international consensus. In this setting, images with defined characteristics are far more useful in clinical practice than a written description alone. For quality assurance and audit, documentation including a comprehensive photographic record is mandatory and helps to set benchmarks and increase unit and endoscopist performance. Without endoscopic pictures, scientific meetings, teaching activities, and public awareness, health campaigns would not be possible.

Photography is an integral part of digestive endoscopy in daily practice. Although the most recent video processors are able to produce adequate pictures, it is important for all practitioners to understand the basic techniques of photography. Since the age of early medical optics to modern state-of-the-art technology (and beyond), many endoscopists have become keen photographers and active players in device innovation. The strong cooperation between physician and manufacturer ensures that the future of photography in endoscopy is bright with possibility.

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Forensic Photography

25

Keith A. Mancini

Contents

25.1 Introduction

Photography has two distinct uses in forensic science, which have been previously defined by the Scientific Working Group on Imaging Technology (SWGIT) in *Section 11 Best Practices for Documenting Image Enhancement*, as Category 1 and Category 2 images. SWGIT terminated its operation in 2015; however the definitions remain in use throughout the field. Category 1 images are used for the documentation purposes, making images to preserve the appearance of evidence. Category 2 images are used for the examination of evidence, making images that will be used in comparison to other images or evidence (e.g., fingerprints, impression evidence, blood stain analysis).

It is the author's opinion that Category 1 images may be taken using the jpeg file format with minimal compression; however, Category 2 images should be taken in RAW or another non-compressed file format such as .tiff. Consideration should be given to the fact that some images taken for documentary purposes may later be needed for comparison.

25.2 Crime Scene Documentation

The primary goal of a crime scene investigation is the collection and documentation of evidence. One of the best ways to document a crime scene is

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Fig. 25.1 (**a**–**c**) Examples of long-range photographs of a crime scene. (Photographer: Kevin MacLaren. Reprinted with permission)

with photography; however, photographic images should also be supplemented with detailed notes.

25.2.1 Safety at the Crime Scene

Prior to entering a crime scene, the forensic photographer/investigator should take several precautions to protect his/her safety and prevent the possible contamination of the scene. These precautions include wearing personal protective equipment (PPE) such as gloves, a hairnet, a facemask, shoe covers, as well as a jumpsuit or coveralls. It is important to change gloves often and wash hands between changes. Photographers should take precautions while handling their equipment at the scene, being sure to avoid touching the camera with contaminated gloves. The photographer/investigator should also be aware of any physical dangers at the scene, such as broken and/or sharp objects. Upon leaving the scene, contaminated clothing and supplies should be disposed properly.

25.2.2 General Crime Scene Documentation

Crime scene photographs should record the initial condition of a scene as well as the location and appearance of the evidence contained within. Several overlapping views must be taken to ensure the entire scene gets recorded. As well, it is important to provide viewers with a frame of reference from one photograph to the next. A common method for documenting a crime scene includes the use of the following views: long range (overall/establishing views), medium range, and close-ups.

Long-range photographs record the overall condition and boundaries of the entire scene. The purpose of long-range views is to establish the location of the crime and its surroundings. It is permissible to use a wide-angle lens when taking long-range photographs. Long-range views should also include areas adjacent to the scene as well as entry and exit pathways. Long-range photographs may include street names, addresses, as well as the surrounding area of the scene. Long-range photographs of indoor scenes include the entire room in which a crime was committed as well as hallways and adjacent rooms (Fig. 25.1a–c).

Medium-range photographs (Fig. 25.2a–c) are used to show the relationship of items to one another and to provide a frame of reference for close-up photographs. Medium-range views should be taken of items in close proximity to one another and should include

Fig. 25.2 (**a**–**c**) Examples of medium-range photographs of a crime scene. (Photographer: Kevin MacLaren. Reprinted with permission)

Fig. 25.3 (**a**, **b**) Examples of close-up photographs of a crime scene. (Photographer: Kevin MacLaren. Reprinted with permission)

a frame of reference from the long-range views.

Close-up photographs (Fig. 25.3a, b) are used to document the condition of individual items of evidence as well as provide greater detail of the evidence. A scale should be present in all close-up photographs (Fig. 25.3a). The scale may include relevant information such as a case number (Fig. 25.3b). Close-up photographs should be taken with a normal (50 mm) to telephoto focal length lens. Close-up photographs may also be taken for comparison purposes (Category 2), to be used for later examination.

25.2.3 Procedure for Documenting a Crime Scene

The initial condition of the crime scene should be documented upon arrival and should be done prior to anything being moved, tested, or processed. The initial documentation may be done during the beginning stages of crime scene investigation, which is commonly termed a "walk through." Initial condition images do not need to be overly detailed. Long-range photographs documenting the entire scene as well as some medium-range photos of obvious items of evidence are all that are necessary at this point. It is advisable to not get involved in taking too many photographs until all the evidence has been identified.

Once the initial documentation is complete, the scene may be processed. It is during this phase that the evidence should be identified and marked and may also be presumptively tested.

After marking the evidence, but prior to collection, the scene should be re-documented to show the location of the evidence. For consistency, it is advisable to re-photograph the scene with views similar to the initial documentation.

The final step before collecting is to document the evidence prior to packaging. Each piece of evidence should be photographed individually to preserve its appearance and record any detail it contains. These photographs should be composed to fill the frame with only the item of evidence, a scale, and any identifier such as a case and item number. There are also items of evidence that may not be collected, such as blood spatter patterns and impressions. These items should be completely documented as well. Techniques to document these items will be discussed in greater detail later in this chapter.

25.2.3.1 Lighting for Crime Scene Documentation

A high-power portable flash is optimal for documenting indoor crime scenes. For long- and medium-range photographs, the flash may be mounted to the camera's hot shoe and pointed at a 45° angle toward the ceiling. This technique is well suited for rooms with a normal height and neutral ceiling. For larger rooms with high ceilings, multiple flashes or studio strobes may be needed. When transitioning to close-ups, the flash should be removed from the hot shoe and re-positioned to best light the subject. A sync cord or other method of communication with the camera (i.e., wireless) must be used. It is also acceptable to use a flash outdoors on bright sunny days, since the flash may be used as a fill light to fill in the shadows and reduce the contrast of the photographs.

25.2.3.2 Homicide Scenes

Every crime scene is unique; however, there are items that if present must be documented. In homicide scenes, be sure to photograph the body from all sides as well as overhead along with any observable injuries. Document the location of any weapons, bullets, casings, and bullet holes. Document any routes of entry and exit that a suspect may have taken, as well as any damage within the scene.

25.2.3.3 Suicide Scenes

Suicide scenes should be treated similar to a homicide until it has been determined that the death is in fact a suicide. Be sure to document any injuries to the body, as well as the location/proximity of the weapon used. In hanging cases, be sure to document the method of strangulation as well as the cordage used and any knots.

25.2.3.4 Burglaries

Document any evidence of forced entry or routes of entry/exit. Document any damage to the establishment, as well as evidence of missing items. Document any evidence left at the scene by the suspect, such as clothing, gloves, cigarette butts, as well as anything that may have been touched by the suspect.

25.2.3.5 Fire Scenes

If possible, document the fire in progress, as well as the firefighting efforts. This may be best accomplished from a distance while using a telephoto lens. Also, document any bystanders since there have been cases where an arsonist will stick around or return to the scene to watch his handiwork. After the fire has been extinguished, document the exterior of the building from all sides and corners. If the structure is not completely destroyed and it is safe to enter, photograph all the rooms within the vicinity of the fire. Be sure to include both sides of the doors and the location and condition of the furniture. Also photograph any burn or smoke patterns along with all heat producing appliances (Fig. 25.4).

25.2.3.6 Motor Vehicle Scenes

Document the surrounding area and buildings to establish the location of the vehicle. Document all four sides and corners of the vehicle. Take close-up photographs of any damage to the vehicle. Document the license plate, VIN, and any decals/bumper stickers on the vehicle as well as any other unique characteristics of the vehicle. If

Fig. 25.4 The interior view of an arson scene

the case involves the interior of the vehicle, completely document the inside of the vehicle including the seats, floor areas, as well as inside the glove compartment, trunk, and any other storage compartment.

25.2.3.7 Blood Spatter Documentation

Blood spatter patterns must be documented in a way that captures the entire pattern, as well as providing enough detail for further analysis. This can be accomplished by photographing the entire pattern in place and then moving in and documenting sections of the pattern at closer range. For patterns where the individual sections are easily identifiable, this is easily accomplished. However, for larger patterns, or patterns which the sections are not easily discerned, use a technique called sectoring as explained below.

1. Prior to documenting the pattern, place scales horizontally and vertically, near the pattern showing its distance from immovable objects such as a wall and the floor.
2. Using a tripod or other sturdy mounting device, document the pattern in its entirety.
3. Separate the pattern into several sectors, approximately 1.5–2 ft. across. The boundaries can be marked using tape, adhesive rules, markers, or string.
4. Re-document the entire pattern to show the location of the sectors.
5. Move the camera closer to the pattern, or zoom in, and document each sector individually. Fill the frame with only that sector and enough overlap to reassemble the pattern. It is advisable to place a smaller, more accurate scale in the photograph of each sector. Be sure to photograph each sector so that the pattern is perpendicular to the camera lens. Photograph each sector from the same distance, as it will be easier to scale the images later (Figs. 25.5, 25.6, 25.7, and 25.8).

Fig. 25.5 Long-range photograph documenting a blood spatter pattern at a crime scene. (Photographer: Kevin MacLaren. Reprinted with permission)

Fig. 25.6 Medium-range photograph documenting a blood spatter pattern at a crime scene. (Photographer: Kevin MacLaren. Reprinted with permission)

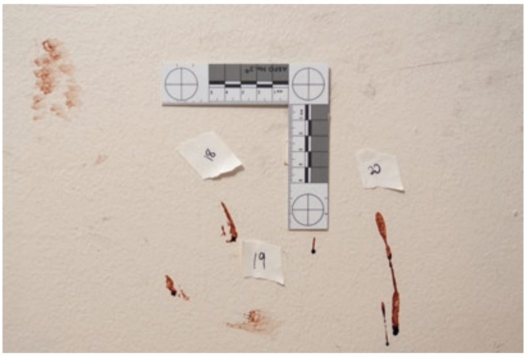

Fig. 25.7 Close-up photograph with scale documenting a blood spatter pattern at a crime scene. (Photographer: Kevin MacLaren. Reprinted with permission)

Fig. 25.8 Close-up photograph of a detail with scale documenting a blood spatter pattern at a crime scene. (Photographer: Kevin MacLaren. Reprinted with permission)

25.3 Evidence Documentation

Evidence is documented for the purpose of preserving its appearance as part of the case record, as evidence in court, or for use by other investigators and analysts.

25.3.1 Evidence Handling Guidelines

To reduce the risk of cross contamination or exposure to blood-borne pathogens, the following guidelines should be followed when handling evidence (Fig. 25.9):

Fig. 25.9 Photographer wearing proper PPE while documenting evidence. (Photographer Brandi Clark. Reprinted with permission)

- Wear disposable gloves, a lab coat, a hairnet, and a facemask.
- Clean surfaces (a 10% bleach solution or ethanol may be used), and change gloves in between items of evidence.
- Do not allow items of evidence to come into contact with one another, especially evidence from a victim and suspect.
- Avoid contact between equipment and contaminated gloves/personal protective equipment (PPE).

25.3.2 General Evidence Documentation

Evidence should be photographed on a clean, distraction free surface, such as a seamless backdrop, butcher paper, or neutral tone exam surface. The lighting should not affect the appearance of the evidence; therefore even illumination is suggested. This can be accomplished using two lights at 45° angles and approximately the same distance from the evidence. Alternatively, one light or flash may be bounced off a light surface, such as the ceiling to diffuse the light. The camera should be placed directly above the evidence or at an angle that best represents and does not distort the evidence. All sides of the evidence should be documented. Close-up images may be necessary to record any important details, such as cuts/tears, staining, fingerprints, or trace evidence on the item.

25.3.3 Highly Reflective Subjects

Photographing reflective objects such as metal, automotive paint, glass, or any mirror surface presents a unique challenge to the forensic photographer. In order to document these items, it is necessary to diffuse the light source. Sometimes simply bouncing the light source or flash off another surface is all that is needed. However, in many situations a device, such as a light tent, is necessary to properly diffuse the light (Figs. 25.10 and 25.11). Light tents can be purchased at many photography supply companies or can be constructed from common materials like paper, or a material such as Savage Translum (also available from photo stores). For smaller items of evidence, a roll of paper, a translum, or even a translucent cup may be used (Fig. 25.12). The item can be placed inside the tent or other diffuser and lit from the outside. The camera lens should be positioned so that it is aimed at the item from outside the tent.

Fig. 25.10 A light tent used for documenting reflective evidence

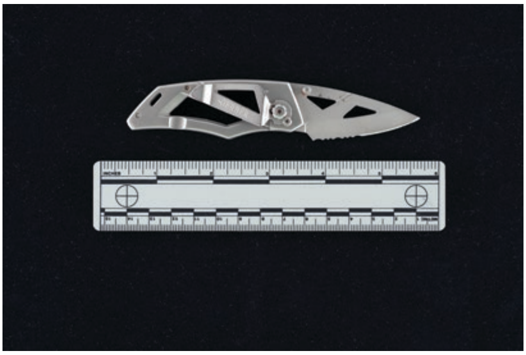

Fig. 25.11 A knife photographed inside the light tent

25.3.4 Photographing Glass Surfaces

Evidence such as fingerprints or impressions is often found on the surface of glass (Fig. 25.13). With proper setup, photographing glass surfaces is not as difficult as it may seem. The first challenge is getting the camera to focus on the sur-

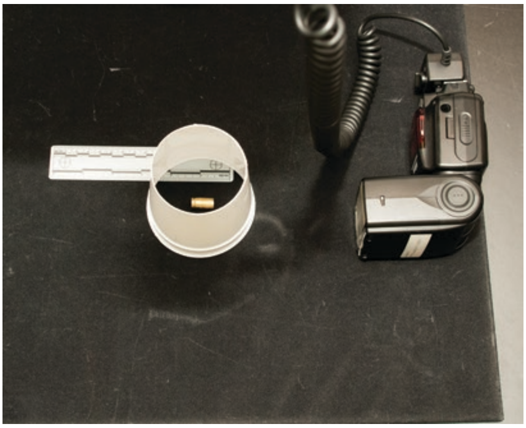

Fig. 25.12 A plastic cup makes a great diffuser for small subjects

Fig. 25.13 Photograph of an impression on glass without the use of a camera mask

face. This may be accomplished using manual focus and mounting the camera to a tripod or other sturdy device. In order to highlight the evidence, place a neutral backdrop behind the glass. The backdrop should be the opposite tone (lightness) as the evidence. For example, if photographing a fingerprint that was processed with black powder, a white background should be used. On the contrary, use a black background for light powders and dusty impressions. To reduce the reflections caused by the glass, use additional background material to create a mask around the camera (Fig. 25.14). This can be accomplished by cutting a hole in the background and inserting the lens through it. The lighting technique will depend upon the evidence, however typically an oblique angle works best. Be sure to position the light so that it does not reflect directly into the camera (Figs. 25.15, 25.16, and 25.17).

25.3.5 Photographing Impressions (E.g., Footwear, Tire Tracks, Tool Marks, and Fingerprints)

Since the images may be used for a comparison examination, there are some additional considerations to take when photographing impressions. The images created will be scaled to a 1:1 reproduction ratio, or actual size, and compared to a known item.

The following resolutions are suggested for each item of evidence at 1:1:

- Footwear impressions 300 ppi
- Footwear impressions containing Schallamach (an abrasion pattern on the bottom of footwear) 900 ppi
- Fingerprints 1000 ppi

In order to determine the maximum field of view that a camera can reproduce, use the resolu-

Fig. 25.14 A simple camera mask constructed out of black matt board

Fig. 25.15 Photograph of an impression on glass with the use of a camera mask

Fig. 25.16 The same photograph as Fig. 25.15 with the addition of a black background behind the glass

Fig. 25.17 The same photograph as Fig. 25.16 with the use of a flash to light the impression

tion suggested above, and then divide the pixel dimensions of the camera (width and height) by that resolution. The result will be the maximum area (in inches) that the camera can reproduce while maintaining the suggested resolution at 1:1. For example, if using the above calculation to photograph fingerprints and the camera has a resolution of 7360 px × 4912 px, you will need to divide each dimension by 1000; therefore, this camera is capable of photographing an area of approximately 7.36 in. × 4.91 in. or smaller while maintaining at least 1000 ppi at actual size.

Larger areas may be documented by dividing the item up into sections, similar to the sectoring technique discussed earlier in this chapter.

At a minimum, the following equipment should be used to document impressions.

- A normal focal length to telephoto macro-lens (*do not use a wide-angle lens*)
- A sturdy tripod, copy stand, or other support
- A portable flash or adjustable light source
- A scale, calibrated or checked against a traceable standard, approximately the same size as the impression

Impression photographs should be captured at the camera's highest quality image format, typically RAW. If RAW is not available, the next best option is to use tiff, and as a last resort, use the highest quality (least compression) jpeg format.

The scale should be placed on the same surface as the impression. At times it may be necessary to remove any material that prevents this, but be sure not to alter the impression.

Using a tripod or other sturdy support, position the camera so that the impression is perpendicular to the camera lens (Fig. 25.18). Doing so aligns the imaging surface of the camera with the impression, making the entire image at the same scale. Compose the photograph so that the impression completely fills the frame, thus ensuring that the maximum detail possible will be recorded (Figs. 25.19, 25.20, and 25.21).

Once the setup is complete, check the focus, and take several images using different lighting angles and directions. It is also suggested to take photographs using the existing or natural lighting of the environment. If shooting outdoors, the sun may need to be blocked, which can be done by creating a shadow that falls onto the impression.

Fig. 25.18 An example of the proper setup for impression documentation. (Photographer: Brandi Clark. Reprinted with permission)

Fig. 25.19 Photograph of a three-dimensional footwear impression in dirt

25.3.6 Documenting Human Subjects

Individuals may need to be photographed for the purpose of documenting injuries, identifying marks on their body, their clothing, or other evidence

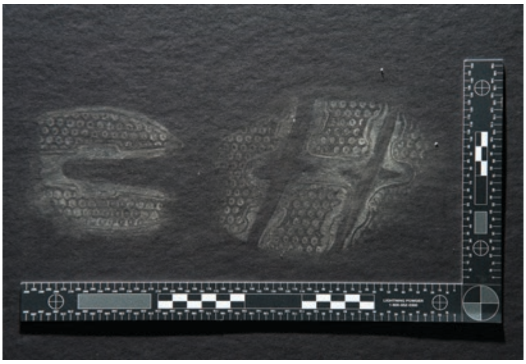

Fig. 25.20 Photograph of a two-dimensional footwear impression made of dust

Fig. 25.21 Photograph of a footwear impression in the snow

located on the body. The subject should be placed in front of a neutral background or wall, without any distractions in the background. Photograph the entire body from the front, the back, and the sides, including the subject's shoes and any head wear. Take medium-range photographs of the subject's face, both sides of their hands, shoes, and clothing. Take medium-range and close-up photographs of any injuries, tattoos, piercings, jewelry, or any other unique characteristics such as a scars or birthmark. If any of the images will be used for comparison purposes, they should include a calibrated scale and be taken at the camera's highest quality.

25.3.7 Bite-Mark Documentation

Bite-mark photographs should be taken with an American Board of Forensic Odontology (ABFO) No. 2 Scale. This is a specially designed scale for use with bite-mark comparisons. The bite-mark should be documented to show its location. Then additional images should be taken at a perpendicular angle using the camera's highest quality setting.

Fig. 25.22 Documentation of the entire body. Frontal view

25.3.8 Autopsy Documentation

Documentation of the body before and during an autopsy provides an important record for future reference. These photographs are typically taken in the presence of a medical examiner (ME) or coroner. The photographer may be directed by the ME; however there are some general photographs that should be taken. Document the front of the body as it was received, from directly overhead. Next, divide the body into halves or even thirds and photograph each section. Take a photograph of the entire face. Document the appearance and condition of any clothing, jewelry, or other evidence adhering to the body. Repeat the same procedure on the rear of the body. These photographs are especially important since the clothing will be removed prior to the autopsy, and it is likely that the body will be washed.

Once the body is clean, repeat the above photographs, also taking medium-range and close-up photographs (Figs. 25.22, 25.23, 25.24, and 25.25) of any injuries, tattoos, or other unique identifying characteristics on the body. If necessary, attend the autopsy, and document any injury to the inside of the body. If for any reason the

Fig. 25.23 Documentation of the entire body. Back view

Fig. 25.24 Documentation of part of the body. Back view, showing gunshot wound

Fig. 25.25 Close-up view of gunshot wound

organs need documentation, they should be placed on a clean, distraction-free surface, and any blood should be cleaned up prior to photographing.

Lighting in the autopsy room can be difficult because of the metal tables and abundance of liquids that will reflect light and cause glare or unwanted reflections in images. A useful technique to diffuse the light is to aim the flash at the ceiling, at approximately 45°. This should adequately spread the light and diffuse it enough to eliminate the reflections. The technique works best with standard height ceilings and neutral paint colors. For smaller subjects, a diffuser can be constructed from paper, other diffusion material, or a plastic cup (as seen in Fig. 25.12) (Fig. 25.26).

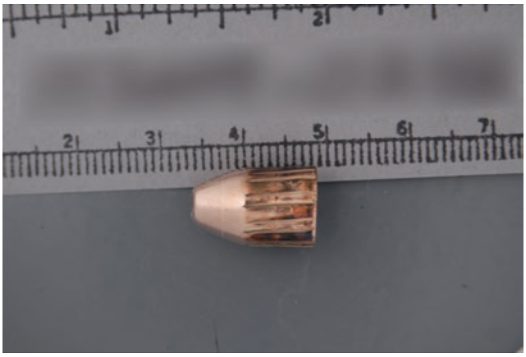

Fig. 25.26 Close-up view of bullet recovered in wound seen in Figs. 25.24 and 25.25

25.4 Alternative Light Source Photography

Beyond the visible light spectrum lies ultraviolet and infrared energy. Imaging using this energy may be used to reveal characteristics of evidence that cannot be seen with visible light. There are several light sources used in forensic science, typically called crime lights, crime scopes, or alternate light sources that can be used in the search for evidence. Forensic light sources help investigators identify evidence through the use of florescence. The light source emits energy of a certain wavelength, the excitation energy, which causes the subject to emit its own energy of a different wavelength. Using a barrier filter corresponding to the excitation energy, a viewer can observe the fluorescence of the substance. The barrier filters are typically supplied by the manufacturer of the light source in the form of goggles; however, camera filters may also be available.

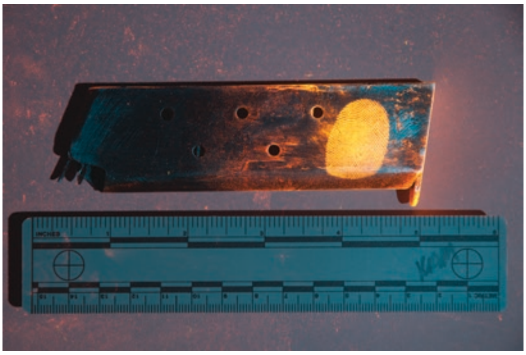

Fig. 25.27 Medium-range photograph documenting a fingerprint developed using fluorescent fingerprint powder

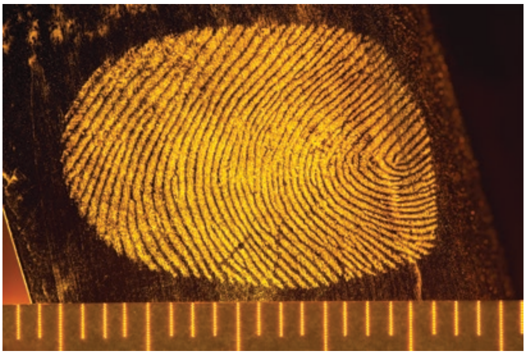

Fig. 25.28 Close-up document a fingerprint developed using fluorescent fingerprint powder

Fig. 25.29 A cleanup attempt of blood on the rear bumper of a vehicle. Picture taken prior to the application of Bluestar®

Fig. 25.30 A cleanup attempt of blood on the rear bumper of a vehicle visualized using Bluestar®

25.4.1 Fluorescence Photography

The fluorescent reaction normally takes place in the visible spectrum; therefore, the photographer needs only a typical camera and the barrier filter to record the results. Filters are typically available from the light source's manufacturer. If a filter is not available, the goggles may be placed over the lens instead (Figs. 25.27 and 25.28).

Place the camera on a tripod or other sturdy mount and compose the image of the subject. It may be helpful to pre-focus the image and disable the autofocus prior to shutting the lights. Place the filter or goggles over the lens and then darken the room. Using the light source, illuminate the subject. Use the camera's light meter to determine the exposure and take an initial image. Evaluate the image for the proper exposure, and then compensate for lightness or darkness in the image. Depending upon the strength of the reaction, it may be necessary to increase the ISO.

25.4.2 Chemilumenescence (Bluestar®) Photography

Bluestar® is a reagent that is used to reveal small amounts of blood that has been wiped away or is invisible to the naked eye (Figs. 25.29 and 25.30). Its main ingredient is luminol. Bluestar® reacts with the hemoglobin contained in blood and produces a chemiluminescent reaction or glow. This glow is usually best seen in complete darkness.

Photographing a Bluestar® reaction requires the use of a tripod because of the long exposure times necessary. Also recommended is an external light source, such as a flash. Before spraying the Bluestar®, setup the camera, and compose the image of the area to be sprayed. Set the camera to manual mode, open the lens to its widest aperture, and set the shutter speed to approximately 30 s. Set the flash to manual mode, and turn the power down to approximately 1/64.

Exposure times vary depending upon the strength of the reaction and size of the area. Prefocus the image and disable autofocus, so the camera does not attempt to refocus in the dark.

After setting up the camera, darken the environment and spray the Bluestar®. As soon as a reaction is observed, open the shutter. It may be necessary to re-spray the area during the exposure, this is acceptable, but care must be taken to not bump the camera. Evaluate the resulting image for proper exposure, make any adjustments, and re-photograph as necessary. The reaction will occur with each re-spray but will become less intense after each application. Also, a pooling of liquid may occur, which may dilute and spread the stain. After the initial exposure, evaluate the image, and adjust the exposure as necessary, To control the brightness of the Bluestar® reaction, increase or decrease the exposure time. To control the brightness of the surrounding area, increase or decrease the power of the flash.

25.4.3 Infrared Photography

Infrared (IR) photography may be used to aid in the documentation of gunshot residue, blood on dark clothing, tattoos, and charred or obliterated writing. IR radiation lies just above the visual spectrum from approximately 700–900 nm.

Digital camera sensors are inherently sensitive to IR radiation; however, most digital cameras have a filter that blocks this radiation. This filter, called a hot mirror filter, prevents the IR radiation from contaminating visible light images. In order to document IR, cameras can be modified by removing the hot mirror filter and replacing it with a filter that transmits only IR radiation. Removal of the hot mirror filter can be done by the user; however, it is recommended to use a company that provides this service. Currently there are several service providers including LifePixel.com and KolarVision.com. Some lower-end digital cameras such as the Nikon D70, D70s, D40, D50, D80, and the D300s have been known to "leak" or pass some IR radiation, making them ideal for this type of photography. A simple test for IR sensitivity involves the use of a common TV remote control. Point the LED at the camera, and activate it by pressing a button, and then either take an image or observe the live view. If the LED illuminated in the image, the camera is sensitive to IR. The Fujifilm company currently produces a camera designed specifically for IR photography. The Fujifilm X-T1 IR is a mirrorless camera and comes in two bundles. The camera is available for forensic professionals only and is available at Adorama or B&H Photo in the USA.

25.4.3.1 Filters

In order to record IR radiation, a filter is needed to block visible light. There are several filters available for this purpose. Different filters transmit different wavelength, so their results may vary. It is recommended to have a few filters available for use in different situations. The following is a list of currently available filters and their transmission wavelengths.

- Kodak Wratten 87 (Tiffen 87, Schott/Heliopan RG780, Peca 904)—740 nm and above
- Kodak Wratten 87c (Schott/Heliopan RG850, B + W 093, Peca 910)—790 nm and above
- Kodak Wratten 87b (Schott/Heliopan RG830, Peca 908)—830 nm and above
- Kodak Wratten 87a (Hoya RM-90, Schott/Heliopan RG1000, Peca 906)—930 nm and above
- Kodak Wratten 89b (Schott/Heliopan RG715, Hoya R-72, B + W 092, Peca 914)—680 nm and above

The following filters may be used to block IR and UV radiation in order to create visible light images using a camera that is converted or specifically made to be sensitive to IR.

- Peca 916
- Hoya UV & IR Cut Filter
- Tiffen Hot Mirror
- B + W UV/IF Cut 486

In order to document IR radiation, a light source which has a high IR output is needed. Typically, light sources that emit a great deal of heat are also high in IR output. Examples include incandescent, tungsten halogen, electronic flashes, and the sun. There are also some forensic light sources that are specifically made to output IR energy.

25.4.3.2 Taking IR Images

The camera should be mounted on a tripod or other sturdy device such as a copy stand. Place the subject below the camera and light it evenly. Avoid bouncing or diffusing the light in any way, as this may adversely affect its IR output. Because of the difference in wavelength, focusing for IR may be difficult. Firstly, autofocus is typically not an option, so use the lenses manual focus mode. Some lenses have an IR focus mark that makes correction for IR easier, simply focus for visible light, and then move the focus point from the visible mark to the IR mark. If the lens does not have an IR mark, either use a small aperture to provide a deep depth of field, use live view to preview focus under IR energy, or take several photos at differing focus depths until the subject is in sharp focus. On a converted or IR camera, the exposure settings may be similar to that of visible light; however, the best way to determine the correct exposure for IR is through trial and error. Using the camera's manual mode, begin at the exposure for visible light, or using the light meter reading, capture an image and evaluate the results for proper exposure, compensating as necessary (Figs. 25.31 and 25.32).

Fig. 25.31 Visible light image of a bullet hole in clothing

Fig. 25.32 IR image of the same clothing showing the pattern caused by gunshot residue

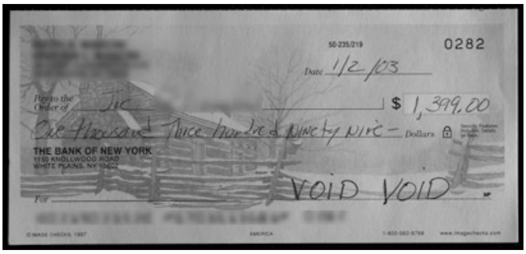

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Fig. 25.33 A check altered with a different black ink: documented using visible light

25.4.4 Infrared Fluorescence

Similar to fluorescence in the visible spectrum, IR fluorescence occurs when a subject absorbs energy and as a result transmits energy in the IR spectrum. This usually occurs when using cyan light (approx. 450 nm) as the excitation source and blocking all but IR energy from entering the lens. This method is often used for document examination. IR fluorescence is well suited for documenting faded, burned, or worn documents as well as documenting differences between inks even if they appear visibly the same color (Figs. 25.33 and 25.34).

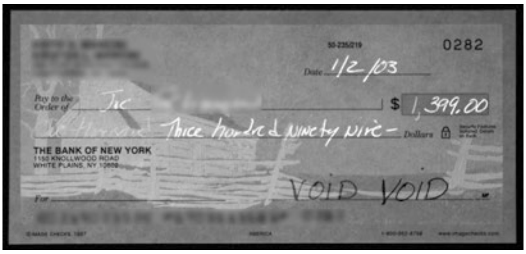

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Fig. 25.34 A check altered with a different black ink: documented using IR fluorescent photography

The setup is almost identical to the setup for IR photography; the only difference is the light source used. Exposure times for this technique are often a few seconds or longer.

25.4.5 Reflected Ultraviolet (UV) Photography

Reflected UV photography is the creation of images using a camera or film that only records ultraviolet energy. While often confused with fluorescent imaging, this technique is quite different.

The use of reflected UV photography to document evidence can provide details that are not visible to the naked eye. UV photography is often used for the documentarian of bruises, bitemarks, and other injuries to the skin and may reveal details of an injury during or after the healing process. UV photography is also used to documenting fingerprints, repainting or overpainting on vehicles, walls, or other surfaces, even when the colors match visibly. UV photography is also useful for low contrast impressions in substances like dust or on a shiny (newly waxed) floor.

25.4.5.1 Equipment

For best results, use a camera that is specifically designed or modified to be sensitive to UV radiation. Some cameras, although not designed for UV photography, may be slightly sensitive to ultraviolet radiation and provide acceptable results. The following cameras have been reported to be slightly sensitive to UV radiation: the Nikon D70, D70s, D40, D50, D80, and the D300s.

25.4.5.2 Lenses

Typical glass camera lens block most of the UV radiation entering them; therefore the best results can be expected from a lens specifically made to pass UV. UV lenses are made of quartz or silica which does not block UV radiation. Examples include the Nikon UV 105 and the Jenoptik UV-VIS and UV-VIS-IR lenses. Other lenses with fewer glass elements, as well as enlarger lenses, have been successfully used for UV photography. The following are some examples of lenses that have been reportedly used for UV photography:

- Rodenstock 60 mm f/4 UV-Rodagon
- Carl Zeiss 60 mm f/4 UV-Planar
- Enlarger Lenses (Nikkor EL series)
- AF-S NIKKOR 50 mm f/1.8G Special Edition

25.4.5.3 Radiation Source

The optimal source will be one that is high in UV energy. Be cautious when working with a UV light source as the energy can be harmful to humans, especially to the eyes. It is recommended that the photographer and subject (if necessary) protect themselves from the UV rays.

Sunlight is high in UV energy; however, it may not be a practical light source for forensic documentation. The sun's angle is not adjustable, it differs throughout the day, and clouds and weather conditions can affect the amount of UV radiation. These conditions make it difficult to repeat or standardize UV photography using the sun as a light source.

Electronic flash units emit a significant amount of UV energy; however, many are designed with filters that block the UV emission. The filters may be removed, essentially converting the flash for use with UV photography.

Studio strobes emit UV energy similar to electronic flashes but tend to be higher in power and may provide enough energy for larger subjects. Particular units may require testing to determine if they will work for UV photography, and as with electronic flashes, some are fitted with a filter that blocks UV energy.

There are several UV sources available commercially. Many forensic suppliers such as

Sirchie, Foster and Freeman, and Tritech sell light sources that are typically used in the search for evidence. These UV sources can also be used for UV photography, but be aware that many have a very narrow band of emission. It is recommended to choose a light source with emission below 500 nm.

Caution: avoid using short-wave UV energy (280 nm and below) on evidence that may undergo DNA analysis; this energy may harm the DNA.

25.4.5.4 Filters

Since most cameras used for UV photography are also sensitive to other wavelengths of light, the energy entering the camera must be controlled. This is done with the use of barrier filters. For UV photography, both a UV passing filter and an IR blocking filter are typically needed since many of the UV passing filters also pass IR radiation. IR radiation leak is a common problem with UV photography, so be cautious that the images produced are not affected by IR.

The following filters transmit UV energy:

- Kodak Wratten 18A
- Schott UG2, UG11, UG1
- B + W 403
- Hoya U-330,340, 360
- PECA 900

The previous filters also transmit some IR radiation so they should be used in conjunction with any one of the following IR blocking filters:

- Heliopan BG-38, 39
- B + W 489
- Kodak Wratten 304 (infrared cut filter)

The Baader U-Venus filter does not require an IR blocking filter, as it transmits very little IR energy. However, the cost of this filter is relatively high in comparison to other filters.

25.4.5.5 Film

Some photographers may choose to use black and white film since it is sensitive to UV radiation and not to infrared. The use of film for UV photography brings other challenges such as focus and exposure determination. While using film, the photographer should choose a small aperture to ensure the image is in focus and bracket their exposures since light meters do not measure UV radiation.

25.4.5.6 Setup

Because of the many combinations of lenses, cameras, light sources, and filters used for UV photography, it is essential to test your particular setup. A relatively easy way to test a UV photography system is to photograph common flowers such as dandelions or sunflowers. Under UV radiation, the center of their petals will appear darker than the outside. It is believed this helps bees, and butterflies locate flowers and their nectar.

25.4.5.7 Exposure

Avoid diffusing or modifying the light as this can remove some portions of the UV spectrum. Compose and focus the image prior to mounting the UV filter on the lens, and then disable the autofocus function of the lens. Similar to IR, there may be a shift in focus for UV photography. This may be solved using the camera's live view function with the filter in place or by testing various focal distances. Place the ultraviolet filter along with infrared blocking filter, if necessary, on the front of the lens. Set the camera to manual mode, and adjust the exposure according to the light source; for flash set the shutter speed to 1/60th second, and the flash to its highest power; for a constant UV source, start with a relatively long exposure, approximately 30 s, and open the aperture to its widest setting. Exposure times will vary greatly depending upon the setup, so be prepared to adjust the exposure settings. Take an initial exposure, evaluate the results, and then adjust the exposure accordingly (Figs. 25.35 and 25.36).

The final images should be converted to grayscale since UV energy lacks any real color value. It is recommended to shoot using a raw file format since there may be some image processing necessary to achieve desirable results. Keep in mind the blue color channel may hold most of the UV data.

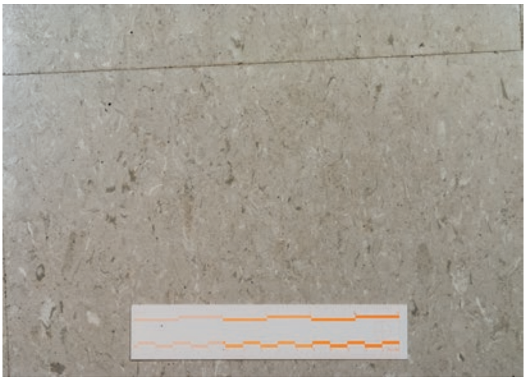

Fig. 25.35 Visible photograph of an oily impression on a tile floor

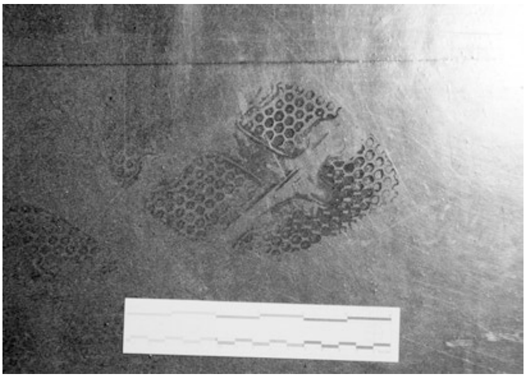

Fig. 25.36 UV photograph of the same oily impression on a tile floor as in Fig. 25.35

25.5 Close-Up and Macro-photography

Since evidence comes in various sizes, it is often necessary to document minute items such as fingerprints, blood spatter droplets, bullets, paint chips, and more. Close-up and macro-photography are very similar techniques, even sharing the same setup and equipment at times. The main difference between the two is reproduction ratio. Close-up photography is typically considered to be anywhere from a 1:10 reproduction, down to 1:1. Marco-photography starts around a 1:1 ratio to approximately 50:1 (50×), or once the subject is on a microscope.

The lens, or lens adaptor, is what enables the photographer to take close-up and macro-photographs. While many lenses can be used to create a close-up or macro-image, the best lenses are the ones designed for this purpose. Typically called macro or micro, these lenses are built with better optics and designed to limit distortions. Also, macro-lenses are designed to focus much closer to a subject than regular lenses will. They are typically much more expensive than non-macro-lenses, however, are worth the investment if close-up and macro-photography will be a common part of your work (Fig. 25.37).

Fig. 25.37 A macro-photograph of a material embedded inside a bullet that was recovered at a crime scene

Other accessories available to aid in close-up photography include supplementary lenses which attach to the front of the lens much like a filter; teleconverters which multiply the focal length of the lens; and extension tubes and bellows that increase the distance between the lens and the sensor.

Creating a close-up or macro-image presents various challenges. Focusing and controlling depth of field are difficult at such close working distances. Motion and camera shake become magnified with the image as well. The use of extension tubes or bellows will decrease the amount of light reaching the sensor, therefore increasing the exposure times necessary. Mounting the camera on a stable platform such as a tripod or copy stand will aid in minimizing several of these factors.

25.6 Photomicrography

Microscopes are an important tool in forensic science and are found in just about every lab. They are used to search for trace evidence, to identify controlled substances, to find semen, and to diagnose causes of death. Documenting what an analyst sees

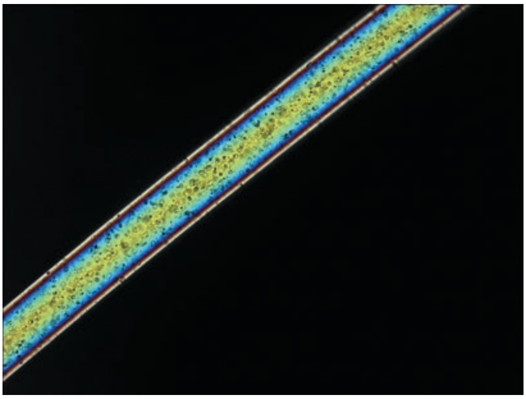

Fig. 25.38 An image of a nylon fiber using polarized light microscopy

on the microscope can be critical to a case, as it allows the analyst to share his or her findings with other investigators and possibly a jury.

There are several ways to capture images from a microscope. There are dedicated microscope cameras, mounts for DSLRs, microscope cameras that attach to the eyepiece, or adapters that allow the use of a cell phone camera. Whatever options you choose, be sure it will produce an image of acceptable quality for your uses. Regardless of the camera, the scope should be clean, well maintained, and set for Khöler illumination.

Several microscopy techniques are often used in forensic science. Light (bright) field microscopy, the technique most commonly associated with microscopy, is used in forensic biology, pathology, and trace evidence. Epi-illumination is used in trace evidence and firearms examination. Polarized light microscopy is used for the analysis of hairs, fiber, and glass. Fluorescence is often used in the examination of fibers (Fig. 25.38).

For more information regarding photomicrography, see Chap. 20 (Dr Peres).

25.7 Digital Imaging in Forensic Photography

For the use of digital photography in forensic sciences, the following best practices should be followed:

- Follow agencies' standard operating procedures (SOP's).
- Always archive the original images.
- Adjustments should be made to copies of the original only.
- Use only industry-accepted processes.
- Image processing steps should be documented so that a competently trained person can achieve similar results. Generally, image adjustments that are applied only to correct the color, exposure, or contrast of an image prior to printing do not need to be recorded, and a copy image is not required. Images that are subject to more complex processes such as noise reduction, sharpening, Fourier transform, as well as color channel extractions should have documentation of the steps taken, including the software used and settings. Trial steps that are not part of the final image or not used for analysis do not need to be recorded.

Many of these best practices can be found in greater detail in the documents produced by the Scientific Working Group on Digital Evidence (SWGDE), and the National Institute of Standards and Technology (NIST) that administers the Organization of Scientific Area Committees (OSAC). It is recommended that any forensic photographer becomes familiar with these documents and incorporates them into their daily workflow.

25.8 Conclusion

Photography plays an important role in the forensic sciences, from simply documenting the appearance of evidence to preserving details for further analysis. Photographs are often used by analysts, investigators, and the court to make determinations about a case. Therefore, it is imperative that the images be a true and accurate representation of the item. Photographers should have the basic knowledge and skills to create images that are an accurate reproduction of the evidence.

Further Reading

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Veterinary Photography Nowadays

26

Esther van Praag and Arie van Praag

Contents

26.1 Introduction: The Animal's Perspective

The body of an animal is a complex structure with many organs and organ systems that are interconnected. When they function properly, the balance is positive and the animal is healthy. When the physiological balance is disrupted, the health condition of the animal is affected negatively. It becomes sick and will need to see a veterinarian. The atmosphere of a veterinary clinic or practice is very different from the normal safe living environment at home or its natural habitat (farm, wildlife). Since it is impossible to communicate in words about what will happen to the patient, unlike with a human being, it is important to place oneself in the perspective of the animal and create a mental picture on how threatening this particular environment can be for an animal. Indeed, animals have amazingly adapted to their natural environment, and, as a consequence, their senses have developed to a far higher acuity than those of man:

- *Hearing*. Animals have an acute sense of hearing, and the range of hearing is broad,

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extending into ultrasonic frequencies. Some animals have a long-distance hearing in order to detect the presence of predators and evaluate the distance between themselves and the source of danger. Their ear pinnae are mobile and can be pointed toward the source of noise. Hearing can be specialized to detect noises coming from a horizontal direction (pointed pinnae of rabbits) or from above (rounded ear pinnae of mice). It is important to keep in mind that some drugs used to calm pet animals do increase their hearing sensitivity.
- *Smell*. Animals have a well-developed sense of smell. The odors of disinfecting products can irritate them. Most animals are also able to detect alarm pheromones released by frightened or suffering animals in the clinical environment.
- *Sight*. Animals are able to detect slight changes in light or movements. These changes can easily startle them.
- *Touch*. Adult animals have highly sensitive pads under their paws that help adapt to the ground they move on and ensure a good grip. In veterinarian clinics, floors and surfaces of examination tables are slippery. Walking becomes difficult, which results in anxiety.

Many animals feel threatened in a veterinary environment. As a result, their senses remain alert to read body language, detect changes in tone, or perceive slight variations in their surroundings. In order to protect themselves and gain some control over the situation, they will respond with apprehension and fear of a potential future danger. This results in a response of fright, anxiety, or aggressiveness. Depending on the situation, the presence of the owner may be indicated in order to reassure and calm down the animal. It may also happen that the presence of a tense and nervous owner will make the situation worse. For those reasons, it is of utmost importance that the photographer keeps in mind that he is asking a favor to a sick, injured, or healthy animal. He must intuitively put effort in relaxation and comfort, which implies being acquainted with the general behavior patterns and particularities of different animal species. His approach and his work method must be adapted to each individual. Indeed, while fully mastering the technical aspects of camerawork, the veterinary photographer can take good-quality pictures expressing the illness of the animal patient only when understanding the behavior and possible reactions of an animal species. This is why veterinary photography should take place in a calm location, in the presence of soft light and without barking of dogs or whining sounds of sick animals. Even so, an unexpected movement, the ultrasonic sound of the photo camera's sensors, or the sounds of the camera shutter may startle the animal, with a risk of stress, aggressive behavior or escape, and injury. Some cameras have an option to minimize the noise of the shutter. If available, it should be activated. Physical punishment or excessive restraint should never be used. Instead, the photographer must be familiar with animals, be tactful, and remain sensitive to the feelings of the animal patient. This includes having an endless patience and a certain amount of luck. This way only, he can gain the trust of an animal and bring it to cooperate and work for him, accept to be handled and be minimally restrained in a position that may be uncomfortable during a short moment. Rarely, an animal is cooperative but apprehensive, using a "bite first, think after" tactic to protect itself. In other cases, the animal is aggressive by nature and will attack any hand or object approaching nearby. In both cases, wearing veterinary safety gloves to protect oneself and the animal is recommended (Figs. 26.1 and 26.2). Indeed, the safety of the photographer,

Fig. 26.1 A thick glove and other protective clothing are occasionally needed to gain the trust of an anxious animal. (Image credit: Arie van Praag)

Fig. 26.2 Wearing veterinary safety gloves ensures the safety of the veterinarian, technician, and photographer. (Images credit: Arie van Praag)

of his assistant, and of the animal should never be put at risk.

For a low-stress photographic session, it is important to work in an orderly way, to be quiet or speak softly to the animal. Loud or high-pitched noises as well as yelling are particularly stressing on all participants. Movements should be slow, never precipitated, abrupt, or hectic. Every animal should be approached carefully, from the side. This way, the individual can maintain eye contact with the person. It will not be surprised and react aggressively. Coming from the front may be assimilated to a penetration of the personal space and flight zone, with an inability to move away. An approach from the back means moving in the blind spot behind the animal's rear. The person remains undetected and may scare the animal unnecessarily when it becomes aware of its presence. During the photography session, the photographer must, furthermore, keep in mind that animals discovering a camera and its miscellaneous accessories for the first time may assimilate the front of the lens as a very big eye observing them and become wary.

Veterinary photography thus involves responsibility, sensitivity to the animal's condition, and respect of the body language and dignity of the animal patient during the photographic session. The animal must be put at ease with the special clinic environment and the material of the photographer before a photography session can begin. Never lose patience!

26.2 Veterinary Photographer

No school trains for veterinary photography. Therefore, the veterinary photographer must be an exceptional person who possesses advanced photographic skills and an excellent knowledge of scientific and/or medical processes in order to implement the following:

- Excellent understanding of photographic equipment as well as video and audio recording
- Advanced knowledge of techniques of camera, lens, flash, optimum exposure, background as well as focus, and composition
- Artistic creativity in order to express a health issue in a visual manner
- Sense for detail and effort and automatisms needed to seize unpredictable moments
- Good communication with the staff of the veterinary clinic
- Proper motivation and positive emotional attitude with animal patients, using affection, trust, and respect
- Compliance with the rules of confidentiality and copyright

These skills are necessary to obtain high-quality images independent of the area of veterinary photography. Indeed, the visual message conveyed in each picture should not lead to ambiguous and wrong interpretation. Along with these photographic challenges, the veterinary photographer must be able to understand and follow the instruction given by the veterinarian. Finally, the veterinary photographer must be dedicated to his work and show sensitivity and compassion toward the sick animal, more than is required in most other photographic specializations.

Basic understanding of anatomy, biology, and/or physiology in a healthy animal is essential to understand the health problem better. A study in life sciences or biology is, therefore, a valuable asset to obtain precise and accurate pictures at the right angle or in a natural position, without optical distortions and misleading information that may cause misinterpretation.

Veterinary photography encompasses a diversity of specialty areas including photomacrography, photomicrography, 2D and 3D imaging (radiography and scanners), or necropsy pictures. The images must be objective and document the medical problem accurately so that they can be used for the following purposes:

1. *Clinical evaluation of the sick animal*. This includes photographs or video recordings of the clinical presentation of the animal patient, detailed photomacrography of diseases and injuries, surgical or veterinary procedures, and pre- and postsurgical status. The images can be used to document a case and monitor a treatment or recovery. They also facilitate consultation with colleagues or communication with animal owners. Securing the obtained images and information about the owner from misuse is the responsibility of the photographer.
2. *Suspicion of a criminal act against an animal*. In the case of veterinary forensic science, rules and standards exist for the photography of cadavers, organs, or other anatomical structures [1–4]. The scientific background and skills of the veterinary photographer will, furthermore, help to document and keep a record of data and images with structured annotations and precise information for later use.
3. *Visual aids for educative purposes or didactic lectures* of veterinary students or staff. Wounds or injuries are often difficult to describe in words. The benefits of images or videos are well established to share details about an illness, a new approach to a surgical procedure, an analysis of the treatment effectiveness, or an improvement of the quality of the care given to a sick animal.
4. *Photographs or multimedia materials for research reports*, dissertations, or publications in scientific or veterinary journals, books, or interactive e-books to illustrate, describe, and/or validate clinical results. When presenting photographs or videos at conferences, it must be taken into account that attendees can take snapshots with their phones and share these on specialized forum or social media. This can threaten intellectual property and copyright rights of the veterinarian describing the case and of the photographer who took the images.
5. *Commercial use*. Occasionally, a veterinary photographer may be solicited by a veterinarian for advertisement and commercially oriented images about his clinic and about his working team, for leaflets for client education, with or without animals. Ethical, practical, and commercial issues should be discussed when using sick animals.

Finally, the veterinary photographer must build a professional network with fellow veterinary/medical photographers, professional organizations, and photo companies. This way information can be shared about the latest development of photographic material and/or methods and help get access to conferences and symposia.

26.3 Photographic Equipment

Experience, tricks, and good communication with the veterinarian are necessary to understand the topic of photography. The following description is the material and method used by the author of this chapter and the photographer, which results in excellent quality images.

26.3.1 Camera

Digital cameras enable to take pictures with an immediate feedback on overall brightness (histogram function), white balance, sharpness, and exposure. Last-minute corrections in the settings can be made to obtain a high-quality picture. The camera is set on aperture mode (A or Av). While the aperture value is set, the camera will select the appropriate shutter speed. The depth of field will be maximized with a small aperture. The light meter of the camera will determine the correct exposure, based on the light in the environment. In the case of veterinary photography, the dominant source of light is usually provided by a source of medical light or a flashgun (TTL metering setting). The former is not necessarily corrected to obtain a natural color.

Focus is very important. Manual focus is privileged as the plane can be chosen. It is, however, a slow procedure, especially when working with wake animals. Automatic focus is rapid, but the camera will decide which surface is ok for sharpness. The most adequate setting is, in general, a selection of spot or semi-spot autofocus, never of several focus points and let the camera chose the site of focus. When the whole animal is photographed, focus is usually set on the eyes for portrait-like images of the animal patient or on the point of interest for a disease, an injury, or an organ (Fig. 26.3). It is recommended to take a slightly wider image frame and crop the picture later, if needed.

Nowadays, smartphones are increasingly used in veterinary photography in spite of the limitations of the phone camera. Indeed, most built-in cell-phone cameras have a moderate- to wide-angle lens. These lenses have one aperture setting only, which ensures a greater depth of field and acceptable sharpness. Digital image processing and image analysis techniques remain limited and difficult. The quality of cell-phone images remains, therefore, an obstacle for its use in everyday veterinary photography and should be used in cases of emergency only; however, developments in this field are extremely fast, and picture quality may soon progress to a very acceptable level. Since smartphones are also used as a phone and may contain various downloaded applications, email or Internet access, hacking, stealing, or inadvertent sharing patient's pictures to nonmedical persons (showing, email, Internet) cannot be neglected. Questions regarding legal issues and protocols such as consent, security, and privacy of the owner/animal patient must be addressed.

26.3.2 Lenses

Independently of the situation and location, keeping an animal in place, without excessive restraint and without movement during several minutes, remains a challenge. For the photographer, this is the time needed to make good-quality pictures with a short or long focal length macro lens. As a consequence, the photographic material must be easy to handle. It includes professional quality lenses for sharpness, clarity, and detail. For a good distance to the subject, a 100 mm focal length (for 24 × 36 mm) or equivalent is a good choice. A macro version allows detailed images up to 1:1. For very detailed images, a micro lens (1:1 up to 5:1)—also called medical lens—can be used.

Fig. 26.3 A veterinary photographer develops his own style while keeping to a standardized approach, e.g., viewpoints of an injured tiny goldcrest (*Regulus regulus*). (Images credit: Arie van Praag)

Depending on the used lens, depth of field may be shallow. This can be corrected by playing with the aperture. It must, however, be compensated by longer exposure times. When using a camera that cannot measure the intensity of light through the lens, correction factors are applied when taking close-up images because the indicated aperture is not accurate anymore.

In case of photomicrography, the camera is mounted to the photo port of the microscope via an adapter.

26.3.3 Flash

Adequate illumination is important. In photomacrography, the use of one or more flashes is the easiest method. Another option is the use of one flashgun with a diffuser attached to the camera or held in the hand. When the light beam is pointed to the ceiling, a natural and even light is obtained without shadows. The intensity of the light beam is adjusted to the circumstances. A good setting when working with animals is 1/64th up to maximum 1/8th. The lighting of the room should be diffuse, to avoid shadows.

Color correctness is ensured by placing a small piece of white paper in an unimportant part of the image. White balance is easily corrected during the image processing steps and will ensure color accuracy.

26.4 Veterinary Photographs

The taken photograph must be visually appealing to the viewer, independent of the type of image (portrait, photomacrography, or photomicrography) and the nature or location of the lesion [5]. When looking at a photograph, the eye should be drawn to the subject area, be it the eyes of the animal patient in a portrait or a lesion in photomacro- and photomicrography, to identify it easily. Therefore, a veterinary photograph needs to have:

- Balanced composition
- Sharp focus
- Correct and even lighting
- Correct framing, centered on the subject area
- Neutral clean background when appropriate
- A measuring device when needed (surgery, biopsy)
- Absence of distracting foreign objects like examination gloves or surgery instruments

While every photographer develops his own style, veterinary photography requires a reasonably standardized approach so that successively taken images can be compared (Fig. 26.3). The viewpoint, lighting, choice of lens, magnification, and positioning of the animal should be similar even if this is difficult when working with different animal species, in environments ranging from sick animals to wounded free-ranging wildlife in field conditions, a veterinary examination room to the operation suite, recovery room, or critical care ward [6].

26.4.1 Image Processing

In order to process digital images, the veterinary photographer must be familiar with up-to-date computer technology and be able to make minimal corrections with photographic design software. Indeed, the use of special laboratories or digital techniques may be needed to highlight a medical problem without distortion of the reality. It is important to note that these programs will only enhance a perfectly taken photograph with correct histogram, sharp focus, minimal noise, and correct color range, correct uneven lighting in microscopy images (vignetting), or improve the background or the image frame. No photographic design software can fix poor-quality photographs.

26.4.2 Safe Storage

Safe storage of the taken photographs as an uncompressed image file in a computer with controlled access is of utmost importance to prevent stealing and misuse. Indeed, these photographs are confidential material. A second (safety) copy kept in a different place of the building ensures against computer or storage failure, accidents, or destruction by fire or water. It is recommended to use an external multi-disk storage box with fail-safe qualities (server) as they have a lower risk to lose data. For large quantities of digital material, a secure commercial storage and Internet service are strongly recommended. The latter have their own secure and fail-safe storage system and a fire-safe protection.

Finally, a veterinary photographer needs to be familiar with radiographic photography, Digital Imaging and Communications in Medicine (DICOM) standard, microphotography, and audiovisual or time-lapse cinematography technique.

26.5 Safe Restraint for Photographer and Animal

Most owners feel responsible for their animals and their overall physical and mental well-being. As a result, most pet and domestic animals have never experienced ill-treatments in their life. Their positive experience with man will allow handling, restraining, and photography fairly easily. Feral dogs or cats, or injured wild animals, on the contrary, do not have this experience. They have learned to distrust man early on in their life or do not wish any contact with man. Protected contact is necessary by means of veterinary anti-bite gloves or through a fence to guarantee the safety of the veterinarian, the photographer, and the assistants (Fig. 26.2).

Once arrived at the veterinary clinic, the animal is taken out of the carrier or is lifted from the stretcher onto the examination table. This can be done by removing the top of the carrier, via the top opening or through the front opening. If the animal is calm, this can be done directly on the examination table. When the animal is frightened and hides in the back of the carrier, or with prey animals like rabbits, the carrier is best put on the floor, before taking the animal out (Fig. 26.4). This avoids a potential fall from the examination table onto the ground if the animal panics and attempts to escape.

Once the animal is safely taken out of the carrier and carried onto the examination table, it is restrained and handled for a proper examination or for photography. Restraint does not mean physical force. An animal should never be grabbed by its limbs and flipped over into position in order to restrain it. It will respond with distrust and hostility in order to protect itself. On the contrary, the current tendency is to use a minimal stress approach. Handling and restraint of animals should be gentle, quick and with confidence, and adapted to the animal species. Indeed, a hesitant approach will often result in vocalization, bite, or scratch.

Soft restraint and handling of any animal into positions adequate for photography are demanding for both the animal and the handler and demand a great concentration. One moment of inattention or negligence can have disastrous

Fig. 26.4 Taking out an animal from the carrier and transporting it safely to the examination table. (Images credit: Arie van Praag)

consequences for the animal, escape, fracture of the spine, or even death, and for the assistant, bites, scratches, quicks, etc., and will shatter the life of the owner (Fig. 26.5). For particularly aggressive individuals, wildlife animals, or zoo animals, sedation or anesthesia (chemical restraint) may be necessary be performed even to the most basic examination procedure (Fig. 26.6).

Amphibians are usually restrained by holding them in clasped hands. Plastic laboratory gloves must be worn to prevent the transmission of zoonotic diseases, parasites, or secretions of the skin that can lead to allergic reactions in man. Some frogs and toads exude small amounts of poisonous fluid or have poison glands behind their eyes that are activated when they feel threatened. Latex laboratory gloves may be fatal to some amphibians [7, 8].

Fig. 26.5 A moment of distraction by the handler allows escape. (Image credit: Arie van Praag)

Reptiles can be handled for examination [9]. Some are very tolerant to be handled and restrained; others react with stress and should be minimally touched. Since lizards or salamanders are very sensitive to stress, they may try to escape. Grabbing the tails of lizards and salamanders must be avoided. It may fall off, which presents a risk of infection for the animal and a loss of its fat reserve. Non-poisoning reptiles like lizards, salamanders, geckos, or turtles can be scooped up, moved, and restrained by hand without any problem. Leather anti-bite gloves or a hook can be used to lift a snake into a holding container or a tube. A lizard can be immobilized in a container with a light adhesive bandage glued to the bottom. Scales of the skin will not be damaged, yet the short immobilization period will ensure good-quality X-rays and photographs.

A bird is easily stressed [10–12]. Therefore, the first observations are done in the transportation cage to evaluate its health status: feathers, position on the perch or on the floor of the cage,

Fig. 26.6 Safety is of utmost importance when photographing zoo or wildlife animals. (Image credit: Arie van Praag)

shape of the body, digestion and droppings, etc. Before removal from the cage, doors and windows of the room are closed to avoid escape. Only then an experimented handler or a veterinarian takes the bird out of its carrier and handles it (Fig. 26.7). Turning off the light may puzzle the bird and enable to restrain it more easily. Methods of restraint for birds vary according to their size, claws, and beak. Wings should be kept against the body with fingers holding them in place, to avoid flapping and attempts to escape. Most of them feel safe when held with hands, but they can also be wrapped in a towel or in an avian restraint jacket. When handling or photographing raptors (hawk, eagle, owls, etc.), the handler must wear protective leather gloves even when the bird is calm and used to the presence of man. These birds dismember their prey with their curvy beaks. As a consequence, an unprotected finger is easily crushed, if not ripped off. Raptors rarely bite, except when stressed. When biting, the sharp hooks in their beak and strong neck muscles will hold a finger and the bird is unable to release it. In such a situation, both handler and bird need emergency help to be released from each other.

Different methods exist to restrain cooperative pet animals: scruffing with cats, leash and muzzle with dogs, and hands with rabbits. In the author's experience, small-sized pet animals (cats, smaller dogs, rabbits) respond well when hands are put around their shoulder and neck region by placing the thumb in their neck region or over their head and keeping the three middle fingers over the shoulder region, accompanied by soft talking [13]. While it allows distraction of the animal by scratching its fur softly, the applied pressure will prevent it from moving away (Fig. 26.8).

Fig. 26.7 Field pictures of a wood pigeon (*Columba palumbus*) entangled in a wire grid before and during its rescue. (Images credit: Arie van Praag)

Fig. 26.8 Different restraint methods on rabbits, taken for educative purposes. (Images credit: Arie van Praag)

Fig. 26.9 Restraint in a towel is well accepted by most pet animals. (Images credit: Arie van Praag)

A further option is to use a piece of cloth or a towel to envelop the animal so it cannot see its environment and panic or attack the person handling it (Fig. 26.9) [13]. Depending on the area that will be photographed, the use of restraint bags is not always possible.

Large animals like horses can be restrained by various methods with minimal stress [14] before taking photographs. The restraint method depends on the personality of the horse and the aim of the examination. A restraint method that works successfully for one horse may bring panic to another. Most safe restraint methods aim to control the head and the neck of the horse, e.g., tying a halter and lead rope and, when needed, restraint devices (Fig. 26.10). These methods bring the person holding the horse close to the powerful defense instruments of this animal: jerking of the head and throwing the person over, teeth and risk of biting, and front feet with a risk of kicking. Therefore, placing a horse in a horse stock platform and a small stall, lifting a limb, or using horse hobbles may be additional safety methods for both the horse and man. Vocal encouragement or intimidation will affect horses and will help calm a timid or nervous horse. Depending on the horse and its temper, chemical restraint (sedation) is a last resort option to calm down a horse or any large animal [15].

Now that the animal is restrained and correctly positioned by the handler, thanks to his experience, the photographer is ready to capture an accurate and precise image of the animal, its health problem or injury.

Fig. 26.10 Safe restraint is a necessity when working with horses, for both the animal and the persons around him. (Image credit: Arie van Praag)

26.6 From Whole Animal Imaging to Photomacrography

Veterinarians see many different domestic small or large animals, exotic animals, and, every now and then, zoo or wildlife animals. Most domestic animals result from centuries of controlled breeding and inbreeding by man, in order to preserve or improve specific characteristics of fur, size, shape of body, meat or milk quality, etc. New breeds have appeared at regular intervals [16, 17].

Consanguinity has decreased the genetic pool and favored the appearance of mutations, diseases, and/or undesirable inheritable traits. In the domestic rabbit, for instance, rabbits with hanging ears (lop) have been selected and bred (Fig. 26.11). The deformity of the cartilage on top of their head (crown) has led to a different attachment of the ear muscles—as compared to straight-eared rabbits—leading to a drop of the ears, accompanied by a narrowing of the outer ear canal. The opening of the ear canal is, furthermore, covered by the hanging ear pinnae, preventing a good aeration of the canal. As a result, lops are at an increased risk of developing outer ear infections [18]. Further well-known inherited anomalies include malocclusion of the incisors in dwarf rabbits or megacolon in checkered breeds (Fig. 26.12) [19–23]. Hence, photography of the whole animal accompanied by detailed anatomy images at the visible (macroscopic) level helps document and share knowledge about a normal individual versus one with abnormal morphological features, independent of the animal species, breeds, or mixed breeds.

In order to document a case properly, a comprehensive set of photographs should be taken of the animal patient. This includes images of the whole animal, its portrait before examination, details of the wounds before treatment, and eventually during and after surgery, X-rays and anatomy features. This is in an ideal situation. The reality is often different. While most animal owners want the best care for their animals, they may not have enough financial resources to pay for all required clinical tests. Bidimensional and three-dimensional imaging is helpful in many cases, but these techniques are particularly expensive. If an animal insurance does not reimburse these costs, an owner may not be able to afford them. When an injured animal is found in the field, photographs of the animal and the surrounding in which it has been found will help assess the situation and rule out or confirm a criminal act.

Communication between the veterinarian and the photographer must be excellent. The veterinarian will provide clear and easy-to-understand information about the clinical situation and the lesion of the animal patient to the photographer, all the while the photographer must be able to understand the problem to document. This means having a grasp of the veterinary language and expressions so that informative pictures can be captured.

Fig. 26.11 Rabbits with hanging ears have a different skull shape when observed from the front or from the top, compared to straight eared rabbits. (Images credit: Arie van Praag)

Fig. 26.12 Knowledge of the anatomy of the skull helps to understand the observed problem and taken accurate photographs. Here a rabbit skull and incisor malocclusion in rabbit. (Images credit: Arie van Praag)

26.6.1 Particularities of Animal Species

Portrait or whole animal photographs are best taken at the level of the animal: kneeling down if the animal is on the examination table or lying on the floor if the patient is on the floor. The unique perspective obtained from eye or below eye-level images may highlight details of the animal's morphology that may otherwise remain unnoticed (Figs. 26.2, 26.3, 26.7, 26.11, and 26.13). Applying the rule of thirds and the equilateral division of the frame into four equal parts will, furthermore, help obtain a balanced composition. The eyeball of the animal should, thus, never be on a midline but in the upper or lower quadrant of the image.

Amphibians are best placed in a small container or terrarium even if this means taking photographs through glass or Plexiglas and reflection of the surrounding and lamps or from the flash. The camera is best equipped with a Polaroid filter to reduce the glare and brightness of the reflection. It is approached as close as possible to the container or the tube till all reflection is gone, before taking photographs of the reptile. Reflection of the photographer in the Plexiglas may be reduced or avoided when wearing dark clothes.

Birds are observed in their transportation cage (Fig. 26.14). These cages have often bars or Plexiglas walls, and photographs must be taken through these. When this is the case, the photographer must bring the camera to a minimal distance of the bars, using full aperture for good results and depth of field to make bars as invisible as possible. Focus accuracy on the point of interest is of outmost importance here, as the distance between the camera and the bird is small. Metal bars or the light-colored anticorrosive coating protecting them may reflect the light of the flash, causing distractions.

When working with mammalian animals, the photographer must be familiar with the behavior pattern of each species. The position and geometry of the eyes will indicate if an animal is a predator like dogs and cats or a prey animal, like herbivores, rabbits, hamsters, or horses. Predators

Fig. 26.13 Eye-level and focus set on the eyes for portrait-like images of healthy or sick animals, here a Bactrian camel (*Camelus bactrianus*). (Image credit: Arie van Praag)

Fig. 26.14 Eye-level images of a rescued wood pigeon (*Columba palumbus*) that remains curious about its new environment

have their eyes facing forward. To obtain expressive and scientific-quality images, both eyes should be seen. Dogs, for instance, obey to voice orders unless very sick or severely injured. A noise or a treat can catch their attention away from the photographer and his camera long enough to take the necessary pictures (portrait or whole body) while they keep their head up and their ears erect. A cat will often act rebellious and will look straight into the direction of the noise, thus, the photographer. Since adult cats are playful animals, they can be distracted by gently and safely moving a toy. Young animals are often submissive and accept the situation without problems.

Prey animals like rabbits, hamsters, sheep, or horses have large, protruding eyes placed high on either side of the head. As a consequence, their field of vision is panoramic (190° for each eye) which allows the surveillance of their environment against predators. These animals should always be approached from the side, with calm movements and with confidence. Verbal restraint can be a great help with prey animals: a soothing, reassuring tone will calm down most animals. Best portrait or whole animal photographs of prey animals are obtained by playfully distracting them while talking to them gently. This avoids fright or escape reactions.

To document abnormalities, illnesses, lesions, congenital anomalies, surgical procedures, or necropsy findings in mammalian animals, a special-purpose lens called macro lens for close-up photography or photomacrography is used (Figs. 26.15 and 26.16). It covers a range from infinite to a 1:1 ratio, depending on the capturing media and the settings. In veterinary photography, the commonly used lens has a focal length of 100 mm for 24 × 36 mm cameras. It permits a safe distance between the animal to be photographed and the camera/photographer. Shorter or longer focal length can be used as well, depending on the topic. The depth of field is similar for all lenses and is given by the relation between the subject, the camera image size, and the lens opening (diaphragm). A lens with a long focal distance can be advantageous when the topic to be photographed should be detached from the background: while focusing on the subject. The background will become blurry, which brings a quieter atmosphere to the image. Playing with the aperture will blend the background even more.

An external source of light is usually required. A flash oriented directly on an animal is controversial, but no scientific studies are available to corroborate or refute any damaging or distressful effect when a flash is used in daylight conditions. The effect of a bright light beam on the eye can be compared with the impaired vision after looking at sunlight. Many animals do not appear bothered by this intense artificial light over a short interval of time during the day or may associate it to lightening during a thunderstorm. This does not rule out that they might be blinded for a short period, especially during the night or in a room with dim lighting.

The camera's built-in/pop-up flash should be used only in a situation that needs immediate pictures, with no better alternative available. Intensity of the light is too much concentrated and oriented onto the subject, resulting in high contrast images with awkward shadows around the animal. When used in macrophotography, the internal flash is so close to the lens that this latter produces awful shadows on the subject. Instead, a flashgun with a diffuser or a portable softbox should be used (Figs. 26.15, 26.16, and 26.17). The light beam of the flash is oriented against a white wall or, better, the ceiling. The reflected light is used to illuminate the subject. This provides a diffuse and even illumination, with little contrast, all over the targeted area. If white walls and ceiling are available, a so-called bounced or indirect flash will have a minor disturbing effect on the animal. Accuracy of colors must be respected. Exposure of the taken images must be verified as overexposure from the flash can lead to the loss of image details, e.g., the texture of a tissue or flashback of eyes or of metallic instruments. If well-detailed shadowless images are needed, a ring flash that fits around the lens can be used.

When highly detailed images are needed, or a tissue is finely detailed, a super-macro, also called micro or medical, lens can be used. Magnification provided by this type of lens ranges from 1:1 to 5:1. The disadvantage of such lens is the short focal length, which makes the distance between the area to be captured and the photographer extremely short. These lenses are, thus, best used on nonmoving topics, anesthetized animals, or necropsy findings.

Close-up photography and photomacrography on live animals require the help of an assistant who restrains the animal in a way that respects its interests all while exposing the area of the body, e.g., incisors by gently pulling back the maxillary lips and genital area (Figs. 26.12, 26.15, and 26.16). Fingers and fingertips of the assistant should remain out of the picture; this is not always possible though. If the animal is affected by a contagious disease, e.g., fungal dermatitis, or when a sterile environment is required, the assistant and photographer must adhere to prophylactic measures such as wearing examination gloves or protective clothes [24]. In all cases, patience is required by all attendees as live or sedated animals may move their head, hide the

Fig. 26.15 Morphological differences, like this double gallbladder, should always be documented with a normal gallbladder to allow comparison. Here in the livers of rabbits. (Images credit: Arie van Praag, Michel Gruaz)

Fig. 26.16 Follow-up in time of an inoperable horned papilloma at the base of the ear pinna in a rabbit. (Images credit: Arie van Praag)

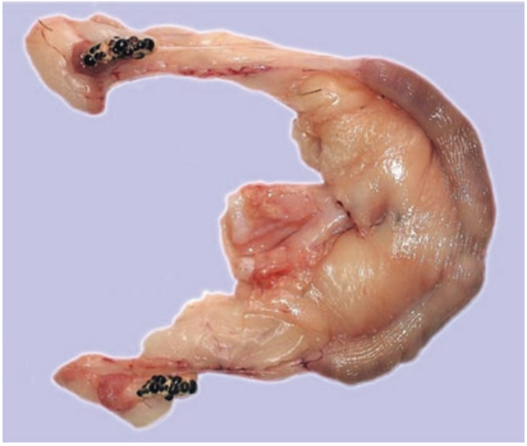

Fig. 26.17 Removed reproductive organ of a female rabbit, showing the two uterine horns and the mesometrium, the fallopian tubes and the ovaries. (Images credit: Michel Gruaz)

targeted area away from the assistant's fingers, or try to escape. Repositioning the animal correctly demands perseverance and time before the perfect image is finally obtained. When documenting a surgical procedure, it is important to replace a blood-stained drape by a clean one before taking pictures. If needed, the background of the picture can be corrected in a photo design software (Fig. 26.17). This avoids shocking images. When it is indicated to include instruments, these are placed in the correct position, but are not operating.

26.6.2 Recording Necropsy Findings

An owner, veterinarian, or referring veterinarian may wish to understand the cause of death of an animal: natural, accidental, euthanasia after a medically untreatable disease, death during a surgical procedure, etc. (Fig. 26.18). In these situations, a basic diagnostic necropsy is conducted. Photographs are made to document the case and explain the findings to the owner or for educative purposes. They are taken while the *postmortem* examination is performed. As a consequence, the photographer is immediately notified when an animal is necropsied in order to take high-quality photographs of the findings under appropriate conditions. This avoids wrong *postmortem* diagnosis. The photographic approach is similar to that on live animals. It is important to note that some products used for euthanasia in animals, like propylene glycol or sodium pentobarbital, will induce *postmortem* artifacts [25]. The former will cause an irritation of the tissues, while the latter will lead to a congestion of blood in the lungs, spleen, heart, and blood vessels. The lungs will become uniformly dark-red, colored and the texture and content of the tissue mimic natural pulmonary edema.

When death of an animal appears suspect or criminal, e.g., neglect (malnutrition, heatstroke), trauma (beating, laceration, drowning), or poisoning, a forensic necropsy of the cadaver can

Fig. 26.18 Incidental finding during necropsies like this double gallbladder should always be documented with a normal gallbladder to allow comparison. Here in the livers of rabbits. (Images credit: Michel Gruaz)

be requested. The discipline of forensic veterinary science is relatively new as compared to the centuries-long experience in human medicine. Training of veterinarians in this field is not included in the veterinary curriculum as yet. As a consequence, veterinary forensic medicine is not as advanced as human forensic medicine. Demands for investigations are nonetheless growing.

When performing a forensic necropsy, the veterinarian and the veterinary photographer must remain impartial to the situation in order to investigate the cause of death and find indications that have led to it. Photographs must be accurate and precise and represent the case correctly. Forensic veterinary photographers usually develop a routine approach for every case, starting with the environment in which the animal is found and whole body photographs in the field, followed by photographs in the examination room, subcutaneous tissues, and finally fluid-filled cavities and internal organs. Legal standards of lighting and rules regarding the position of the organs in the photographs must be respected [26–29]. Bleeding may happen during a necropsy. Any blood stains must be removed before photographs are taken to avoid artifacts and wrong conclusions (Fig. 26.17). The photographic material and the forensic pathology report will serve as evidence in a court of law.

26.7 Light Microscope Photography

It is often assumed that a veterinary photographer sees the whole animal patient and performs macroscopy images of wounds, injuries, tissues, observed anomalies, etc. In fact, light microscopes have been used in veterinary medicine since a few centuries already. It is, however, only since the second half of the nineteenth century that treatises describing the use of a microscope in veterinary practices have been published. The invention of the field microscope, also called traveler's microscope, has brought great improvements in the diagnosis and the identification of parasites and microorganisms in farm animals (Fig. 26.19). These were responsible for a decreased productivity for farmers and were considered public health hazards. The field microscope has also been used to analyze tissues samples.

Nowadays, the use of a light microscope has expanded to different fields of veterinary medicine: practice, research, and analytical testing laboratories. The photographer will assist the veterinarian with binocular and light microscopy, taking photographs of microscopic findings.

In practice, light microscopy is routinely used for:

- Analysis of blood, body fluids, and fresh blood smears

Fig. 26.19 From live photomacrography to binocular photomicrography: tick walking on the fur of a rabbit and engorged tick removed from another rabbit. (Images credit: Arie van Praag)

- Broken hair shafts, dandruffs, parasites living on or deep within the skin, parasite eggs or waste products on the surface of the skin and in the ears, and intestinal parasites in the feces
- Skin scrapings or smears for bacteria, dermatophytes, and yeasts
- Basic urinalysis and presence or absence of sediments, proteins, red or white blood cells, and bacteria
- Cytology after fine needle aspiration (FNA) of lumps, bumps, or tumors and swabbing or impression smear of pus, eosinophilic lesions, or other liquid exudates

These rapid diagnostic tests (RDT) aim to obtain a preliminary diagnosis or an emergency veterinary screening for treatment planning while waiting for the result of analysis of other tissue samples or histopathology from the veterinary analytical laboratory. These specialized centers use specific dyes and staining methods and optical microscopy technique possibilities like phase contrast, dark ground or fluorescence microscopy, or even electron microscopy if needed.

Light microscopy is, moreover, used in veterinary research, e.g., histology, differences or similarities of specific tissues from different species, study of parasites, and research on artificial insemination (Fig. 26.20).

Digital photomicrography is a very valuable tool to document the findings and add them in the record of the animal patient or for legal procedure if a criminal act is suspected [5]. The obtained images are, furthermore, a precious help to educate veterinary students, laboratory technicians, or veterinarians or share with a specialist for interpretation or advice.

The system used by the author includes a light microscope with an extra camera port adapted for photography, an adapter that fixes the digital camera to the microscope, and a digital camera with display, whose lens can be removed, to fix it to the adapter. A real-time image from the microscope is obtained via the "silent Liveview" option. While this setting is aimed at taking photographs of wildlife by reducing the noise of the shutter, "silent Liveview" minimalizes the mechanical vibrations caused by the shutter's movements, avoiding a loss of precision of the image. This is particularly valuable when higher magnifications are used (Fig. 26.21). The autofocus mode of the camera is very helpful. Yet, to obtain a high-quality and precise image, manual adjustment of the focus can be made with the fine focus knob of the microscope. If the specimen mounted on the slide is thick or dark, lighting of the microscope is adjusted or put on maximum. If this is not sufficient, the ISO setting of the camera can be increased.

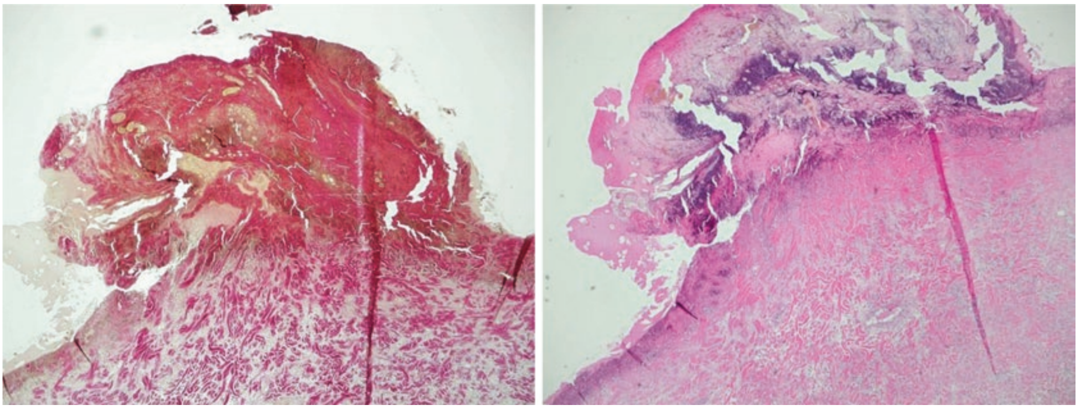

Fig. 26.20 Different coloration methods of a skin biopsy sample from crusty lesions on a rabbit in order to identify the pathology

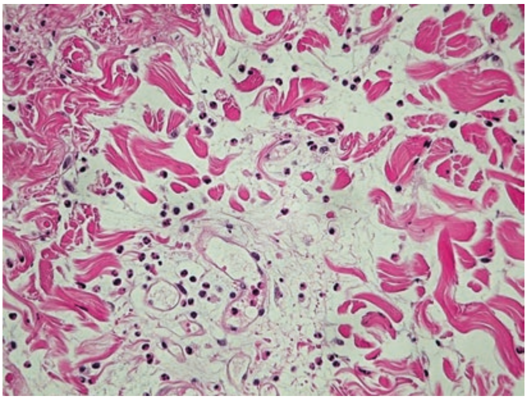

Fig. 26.21 Higher magnification—here an infiltration of eosinophils deep into the connective and scar tissues of a rabbit—require a stable photography system

Depending on the type of microscopy, the photographer will have to compromise on the resolution. If the intensity of light is low, as for fluorescence microscopy, more light is required and, thus, higher sensitivity settings (ASA) are chosen, which will result in more noise. Samples seen with a light or phase-contrast microscope have usually a high intensity of light. Consequently, a lower sensitivity setting is chosen, which goes together with less noise.

Image editing software can bring small corrections to the obtained photographs such as cropping, sharpening, correcting darker lighting of the corners (vignetting), or panorama stitching to adjoin several photographs when the microscopic specimen is larger than the field of view.

26.8 Non-invasive Pre-Clinical Imaging

The use of non-invasive methods for diagnosis and therapeutic monitoring has been appealing to veterinarians since the mid-twentieth century. Radiography and ultrasonography are used as major diagnostic tools since decades in small and large animals.

26.8.1 Veterinary Radiography Equipment

Radiographic equipment has initially been designed for human medicine. Modifications and adaptations were necessary for veterinary medicine purposes. As a result, different categories of machines have been constructed to fit the needs of veterinarians:

- Fixed X-ray machines are powerful with a big transformer and high output (300 mA/120 kV up to 1000 mA/200 kV). They are placed in a

Fig. 26.22 Digital X-rays of the skull of a healthy rabbit

radiation-protected room. These machines can be used for the examination of large and small animals (Fig. 26.22).

- Mobile X-ray machines have a relatively high output (between 90 and 125kv and 40 and 300 mA, or 120 and 200 kV and 300 and 1000 mA). They can be moved within the clinic, which makes them suitable for use in large animals as well as companion animals. Positioning of the arm and, thus, of the X-ray tube is limited due to the high-tension cables that link the X-ray tube and the transformer. This limits radiography of horses to the head, neck, spine, trunk, and upper-limb regions. For small animals, they can be used for all types of radiographic examinations.
- Portable X-ray machines are lightweight, aimed for easy transportation. Proper diagnosis is difficult as the output is relatively small, ranging from 70 to 110 kV and from 15 to 35 mA. Portable X-ray equipment is used mainly to image the lower limbs and feet of large animals such as horses and cattle. If no alternative is available, these machines can be used for body X-ray on small animals too.
- Dental X-ray machines for companion animals are mainly used by veterinarians with a specialty in animal dentistry. The covered oral area is small and the output limited to 10 mA/70 kV.

For safety of the animal patient, the above-mentioned types of radiography equipment use a standardized set of hard X-rays with a higher frequency, a wavelength below 0.2–0.1 nm, and lower energies ranging from 20 keV to 150 keV, according to the nature of the tissue.

26.8.2 Bidimensional Imaging

Over the past decades, veterinarians have been using conventional bi-dimensional radiography with film technology. This requires special equipment such as cassettes that contains the sensitive film and intensifying screens for film irradiation and a darkroom with a variety of chemicals to develop the film and correct archiving in airtight storage boxes. During the 1960s, machines appeared that processed the film automatically and rapidly (Konica). Starting in the year 2000, computed radiography (CR) started to be used in veterinary medicine. Very slowly, this technology employs a reusable phosphor imaging plate and a grid that removes scattered X-rays during the X-ray exposure. A digital image is created by placing the cassette in a scanner and sending the image file to the computer. The cassette and the scanner need to be clean to obtain good-quality radiographs. Any dirt present will leave white spots and, thus, artifacts. A further disadvantage is the appearance of grid artifacts and aliasing (Moiré fringe pattern) when exposure to X-rays is too low. Nowadays, the use of digital radiography (DR) is more and more common in veterinary practices (Figs. 26.22 and 26.23) [30]. Most digital X-ray detectors possess an automatic control of the exposure, acquire the images, and transfer them to a computer via a network cable or Bluetooth for viewing. The only parameter that remains critical is the correct positioning of the animal patient.

Some veterinary practices still use film radiography and have a darkroom with equipment and chemicals needed to develop films. In this case, film radiographs can be digitalized by placing them on a vertical or horizontal medical X-ray view box. The digital camera is placed on a tripod and aligned (1) in parallel to the lighting box and (2) with the center of the film X-ray. To avoid any shaking from the long exposure time, the camera can be set on self-timer. All lights in the room are turned off while taking the photographs. As alternative, a copy stand for digital camera—as used in libraries to photography books—can be placed over the view box.

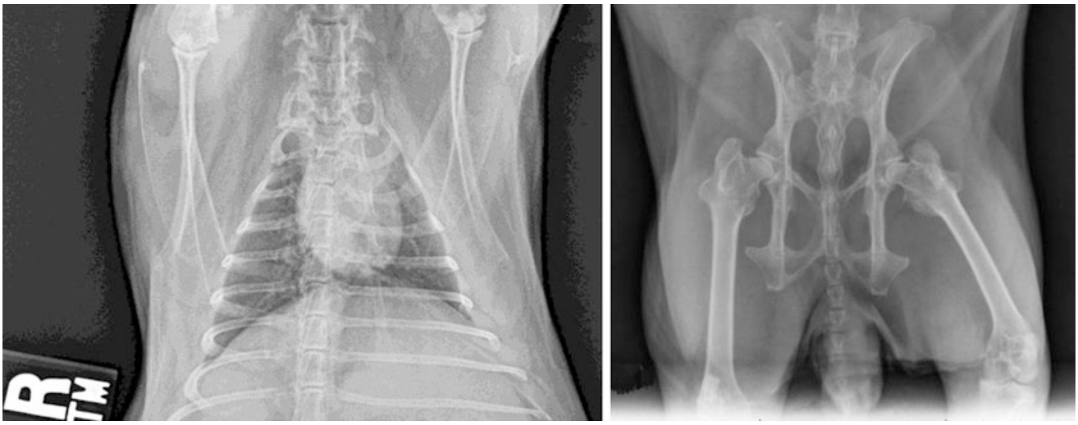

Fig. 26.23 Set of digital X-rays of the chest and hip regions of a healthy rabbit

Fig. 26.24 CT scan image from a scan series showing the chest, lungs, and heart in a rabbit

26.8.3 Three Dimensional Imaging

Non-invasive cross-sectional 3D imaging methods are increasingly used in veterinary diagnostics or research applications. High-resolution ultrasound, magnetic resonance imaging (MRI), and computed tomography scanning (CT scan) provide high-quality images of the body's morphology and topography in 2D or 3D. Radiography, ultrasound, CT scan, and MRI sensitivities and specificities complement each other and should, ideally, be used altogether on an animal patient in order to obtain a complete clinical picture of the pathology (Fig. 26.24). In daily veterinary medicine, there are still many limitations:

- Access to veterinary CT or MRI equipment remains limited in many countries, if available at all.
- Veterinary radiology is a fairly new discipline and specialists may be a handful only in a country. Difficulties may arise if the patient belongs to a less common animal species, like exotic or wildlife animals.
- Time to analyze the complex images accurately.
- Imaging tests are expensive and owners may be unable to support the costs of more than one imaging test.
- MRI and CT scans require a complete immobility of the animal patient. General anesthesia is necessary, which adds to the costs for the owner. When the underlying conditions or illnesses do not permit it, the animal may be sedated and placed in a small cardboard box to perform the scan even though results of the test may not be as good as those obtained on an anesthetized animal.

Since the turn of the twenty-first century, powerful molecular imaging techniques have become increasingly accessible for veterinary medicine in Europe, less so in the United States. They make use of accelerated particles for high-resolution nondestructive imaging on live animals or during necropsy: proton imaging, dynamic neutron radiography, and positron emission tomography (PET and PET/CT) imaging

[31–33]. The latter technology is still in early stages in veterinary medicine. First positive results have been obtained in veterinary oncology with an individualized approach in the treatment of animals suffering from cancer or in the diagnosis and assessment of veterinary orthopedic diseases. Recent developments in 3D color X-ray imaging techniques make use of hybrid-pixel-detector technology (Medipix3) initially developed to track particle in the Large Hadron Collider at CERN (Switzerland) [34]. This new-generation x-ray technique is currently used in human clinical trials to study cancers, bone and joint illnesses, as well as vascular disorders (Fig. 26.25). high-resolution, clear, and precise images contribute to accurate diagnosis. As with X-rays, the higher the frequency, the higher the resolution; the smaller the particle, the higher the resolution, including a different set of penetration roles. Undeniably, this technique will one day be used in veterinary medicine too.

User-friendly image optimization software is available to optimize the images obtained with the different imaging techniques, using parameters including:

- Grayscale latitude optimization
- Contrast enhancement and brightness
- Unsharp mask and noise reduction filters
- Correction of over- or underexposed images
- Edge restoration

The obtained digital imaging results can be saved into a variety of formats, including the

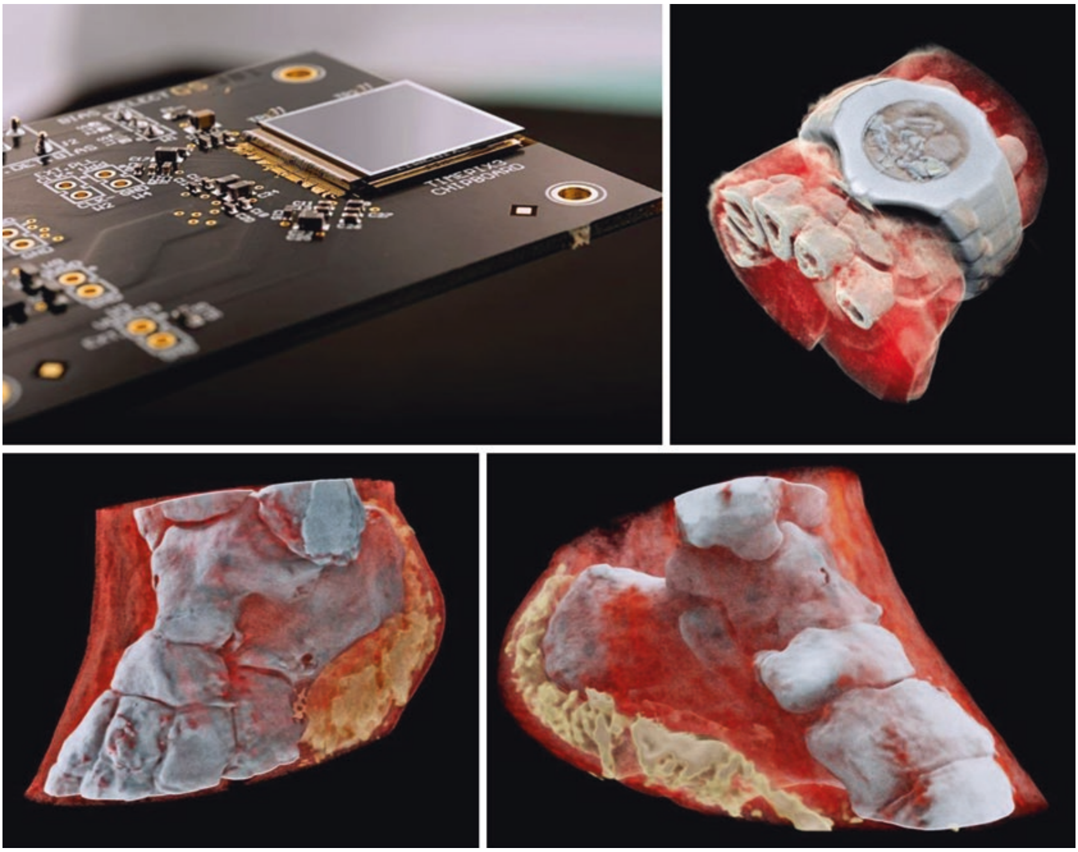

Fig. 26.25 Timepix3, one of the read-out chips of Medipix. Here in the livers of rabbits and the obtained results: a 3D image of a wrist with a watch and an ankle right and left with bones in white and soft tissue in red. (Images credit: MARS Bioimaging Ltd.)

Digital Imaging and Communications in Medicine (DICOM) format, a communication protocol that has been developed for human medicine. It saves tightly compressed jpg or run-length encoding (RLE) types of images together with pixel data and information about the identification of the patient, the used modalities, their display formats, and the date of the clinical study. The DICOM system will, furthermore, attribute a tag to each image in order to classify it.

Standardization of the DICOM format enables to view digital clinical images independently of the used veterinary equipment and manufacturer. DICOM has, therefore, been adopted as an imaging standard in human medicine. Veterinarians showed an increased interest in digital imaging, but met various difficulties when using the DICOM system. Indeed, they treat a large variety of animal species and breeds, with many different characteristics. In 2006, the American College of Veterinary Radiology (ACVR) and a DICOM Standards Committee decided to modify the human-based DICOM attributes to veterinary needs. Veterinary identification tags were added, which include:

- Identification of the animal patient: owner, name of the animal, ID, and date of birth if available
- Characteristics of the animal patient: species, breed, sex, or neutered
- Anatomy of the animal patient during the clinical imaging test
- Positioning during the imaging test
- Classification of the procedure

To limit the amount of free text accompanying the image, codes were introduced for the description of breed, species, gender status (e.g., yes or no for neutered), and breed registration number. A German study shows, however, that most German veterinarians do not use the veterinary identification DICOM tags correctly 10 years after their introduction [35].

The DICOM format is associated with the picture archiving and communication system (PACS), which allows a secure storage, archiving and retrieval of electronic images, as well as the digital transfer of clinical images with documents about the animal patient. Secure and rapid distribution of images via free or purchased DICOM/PACS software is possible, thanks to broadband Internet access. DICOM files can also be saved on a CD-ROM with an embedded DICOM viewer.

Digital imaging technology requires a computer with a high-quality graphic card and a high-quality medical grade monitor with a very high resolution and able to display 1.074 billion gray tones, as compared to 16.7 million for a high-quality commercial screen. The DICOM format incorporates a grayscale standard display function (GSDF) for correct display of grayscale images on monitors calibrated to the GSDF curve and correct printing on film printers.

This evolution presents many advantages in veterinary medicine [36–39]. Consultation with other veterinarians is increasingly demanded for the interpretations of 2D or 3D scan images, or to confirm a diagnosis [40, 41]. Veterinarians must, however, possess advanced skills in computer use and be knowledgeable in the different imaging techniques in order to interpret the obtained images correctly.

26.9 Conclusion

Veterinary photography is more than photography of animals, photomacrography of their illnesses or diseases, or photomicrography. It is a special pro tempore relationship with an animal that does not understand the demands and needs of the photographer such as positioning or staying quiet. It is the amazing experience of seeing many animal species, with their specificities and special needs. It is the experience of developing a relation of confidence in an environment that is intimidating to the animal patient. It is the experience of having the responsibility of a living being and giving priority to veterinary care above that of taking photographs. It is a lesson of respect of the animal, humility, and patience. Therefore, veterinary photography cannot have the consistent and homogenous approach and standards as in human medicine photography. It needs adaptation, ingenuity, and originality in the approach to each individual animal patient.

Equipment used in veterinary medicine is modern in most practices and clinics. Even so, it lags behind on equipment used in human medicine. This also affects veterinary photography.

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Intraoperative Photography

27

Paola Pasquali

Contents

27.1 Introduction

Surgical procedures are occasionally the focus of interest and require photographic documentation. Such images will be used for medical records, to communicate techniques to other colleagues and students, and for research purposes. Even surgical approaches can be selected by analyzing preoperative images [1]. Appropriate consent should be obtained; fortunately, most patients will not refuse to be photographed [2].

When speaking of surgical procedures, the first word that comes in mind is sterilization. Surgical photography does not escape from the same restrictions imposed on any person or material that is taken into a surgical area. There are restrictions that are patient, physical area, and photographer dependent.

27.2 Intraoperative Photography

There are certain considerations that make surgical photography different from conventional medical photography [3]. The patient under local anesthesia tends to stay still and under general anesthesia is completely immobile. This is an advantage for the photographer as motion will not be an issue. Among the disadvantages are the restrictions imposed by the required sterilization of the working area, the distance that the photographer should maintain from the operating area

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and dressed surgical personnel, and the light used to illuminate the procedure.

27.2.1 Patient Related

In regard to the patient, signed consent is required in advance as in any other medical photographic medical registry. Under special circumstances, photographs can be taken without consent one being having the patient under general anesthesia. A picture can be taken without consent as long as it is asked for afterwards. If the patient refuses to give it, then the images should be destroyed [4].

27.2.2 Physical Area: The Surgical Scenario—Procedure Rooms vs. Operating Theater

A procedure room is defined as a room where minor surgical procedures are performed which mostly require sterile equipment but the physical space is not aseptic. Dental, many dermatologic, and some plastic surgery procedures are performed in this type of areas. The operating room (OR) instead is a facility where surgical operations are carried out. They have an aseptic environment, are usually windowless, and maintain controlled temperature, humidity, and pressure and light conditions. Accordingly, restrictions related to the physical area will be different, being the operating room more restrictive because the required aseptic environment.

Walking in and out of an OR is not permitted unless appropriate cloth and cleaning are performed. Even the door through which the photographer can pass to enter or exit must follow a protocol. Understanding these rules will avoid unpleasant situations with the surgical team and unnecessary exposure of the patient to dangerous situations.

If the photographer requires bringing in any electrical material in the operating room, it will be convenient to check if it complies IEC 60601 (a set of technical standards for the safety and essential performance of medical electrical equipment) [5]. Photographic cameras should not give any problem in this regard.

27.2.3 Photographer Dependent

Sometimes surgical procedures are documented in partially aseptic areas. Such is the case of most dermatological and dental surgery, some plastic surgical procedures, and minor general surgery. In other occasions, a medical photographer is asked to enter a surgical theater with strict sterile procedures and where personnel and equipment need to meet certain standards of sterility and safety.

When working in procedure rooms, the photographs are sometimes taken by the surgeon or assistant surgeons and nurses. In this case, sterilization should be guaranteed either by changing gloves every time the camera is used. Although it is possible, it is time-consuming. The camera should be placed on a different table, in a safe place to reduce chances of accidental drops.

Another option is to place the camera on a specially designed wheeled stand and connect the camera to a remote shutter (placed on a sterile envelope) or pedal and put the camera in autofocus. This is the ideal setting for a single surgeon procedure that does not have an assistant to take the pictures. The wheel will facilitate moving the camera around and placing it in the correct area and taken into different working areas. These arms usually come with sterilizable handles. The disadvantage is to accidentally hit them and drop the camera.

Finally, there are special arms that can be fixed to the roof of the surgical area. This is ideal for a one-working surgical area. As all the above-mentioned stands, they can be used for both cameras and video cameras. Roof arms are ideal for safety: no accidental hitting and dropping; they are space savers and have also removable and sterilazable handlers. An external monitor connected to the camera will be required for visualizing and selecting the area that wants to be photographed. Again, wireless remote control shutter release (to be placed in the appropriate sterile case) or pedals are available.

When working in an operating room, a designated photographer is usually in charge of taking the required pictures. If such is the case, this person will need:

- To know in advance what type of photos are required. It is important to have previous knowledge of the surgical procedure.
- Get all the equipment ready beforehand as it will be inconvenient or even impossible to go in and out for missing parts.
- Prepare accordingly scrub hands and use appropriate surgical gown, mask, and cap.
- Get all the settings ready: adjust white balance, use the appropriate lens, and have a stool handy. If external lights are going to be used, set them in place in advance.
- Pay attention to the instructions given by the surgeon.

The suggested position for the camera operator is directly behind the surgeon, shooting from the surgeon's view [6]. If not possible, zooms will help capturing close-ups.

Finally (last but not least!), the assigned photographers need to feel comfortable with surgical procedures and not be susceptible to the site of cuts and blood and know what to do and not to do under an emergency situation.

27.3 Equipment

Most equipment for conventional medical photography can be used for surgical photographing. Make sure to have enough batteries and memory cards with you before entering the surgical ares. DSLR cameras are ideal to work with and should be set in manual control; have a prime lens of 100 mm for close-ups, 60 mm for wider field of view and wide angle prime lens if in need to picture the entire surgical field. Zoom lenses will be required in surgeries where the photographer needs to position at a distance, due to sterilization protocol. Aperture should be at around f/8 and shutter speed above 1/60–1/100. White balance should be adjusted to the ambience light. A tripod might be needed as light might not be sufficient or have an inadequate temperature. In general, flash should be avoided as it can be disturbing for the surgeons and the rest of the personnel. An additional disadvantage is the it can generate a shining image over instruments [7]. If in need to use it and under the surgeon's instructions, it can be used just to take a picture; it is then suggested to use flash off the hot shoe and hold it by hand to minimize shadows [3].

For procedure room, waterproof cameras can be immersed in povidone-iodine solution [8] or placed in a waterproof case [9]. The latter are available for specific camera models. The disadvantage is the cost as they tend to be expensive.

To take pictures from a colposcope, surgical microscope, or slit lamps, there are special adaptors sold in the market. Sony makes adaptors for full frame, APS-C, and 4/4′ sensors.

For procedure rooms, it might be convenient to install a camera arm at the roof or have a special standing pole. Lamps can be adapted in a second arm and with specified temperature light. They come with removable and sterilizable handles (Fig. 27.1) [10]. Cameras can be shut by using a wireless remote control or a pedal. Images can be viewed from a monitor to select the desired viewpoint.

It is convenient to clean the camera before and after surgery using an antibacterial alcohol wipe. If possible, leave a camera or smartphone just for intraoperative photography, in a safe place in the operating theatre.

27.4 Viewpoint

The ideal viewpoint is the surgeon's. When possible, pictures should be taken standing behind the surgeon, not touching or disturbing her/his work. In some surgeries, this is simple not possible. Extreme care should be taken not to lose balance. Standing on a stool help to gain a better view.

Before shutting, ask the surgeon or assistant to clean the field of view from excess blood, gauzes, and instruments. Hooks and retractors can be useful to make deeper structures visible. The

Fig. 27.1 Different optional arms to place a camera and lamps for surgical photography. Left to right: (**a**) W-Arm 2; center, (**b**) S-Arm 2; right, (**c**) Twin Arm (Courtesy of Sonyware medical, All rights reserved)

surgeon and assistant need to work with the photographer as a team. It is important to let the photographer know what photographs are important for the surgeon.

It is convenient to take different angles. An immediate pre-surgical and post-surgical photo should be taken.

Using the surgical drapes as backdrops is a good idea. Sometimes, even the adequate position of somebody dressed with surgical gown will work!

27.5 Specimens

Taking a picture of a specimen is simpler because it can be placed over a clean plain surgical paper on a table. It can be put in the correct position with any excess blood or liquid pat dried. A backdrop should be placed for lateral views and if possible a scale placed alongside (although digital scales are ideal).

27.6 Smartphones

The tendency today is to use smartphones even for surgical photography [11]. The advantages include light weight, easy to use, and possibility to place in a sterile sheath to protect both the patient and the phone. By using the appropriate light over the surgical area, good images can be obtain as mobile photography quality increases when there is a good light source. New smartphones have better cameras, and quality is becoming quite good. However, they do not substitute a DSLR camera for sharpness and richness of detail. Depending on the use, a good smartphone picture might be sufficient.

27.7 Conclusion

Operating room photography is usually performed by a specialized photographer. The best work will be done by a person that has knowledge on the surgical procedure and the surgical team expectations.

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Part VI

Beyond Conventional Photography

Dermatological Imaging: A Survey of Techniques

28

Adrian Davies and Jonathan M. Crowther

Contents

28.1 Introduction

Photography, both analogue and digital, has been used for the recording of medical conditions since the late nineteenth century. Since then, various techniques have been employed to enhance often faint signs or make visible conditions that cannot be seen by the human eye. In 1864, Hermann Vogel, a German chemist, photographed a woman using a glass plate sensitive to just ultraviolet (UV) and blue light. The resulting plate showed several black spots on the woman's face, invisible in normal light. The woman was later found to have smallpox [1]. The significance of Vogel's discovery was not fully recognised at the time, and it would be another 40 years before invisible radiation photography was truly recognised as a technique.

More recently, various research projects have investigated whether photographic techniques can be used to aid early diagnosis of skin conditions such as melanomas [2, 3]. This research activity has declined in recent years, partly due to the introduction of digital technology, which makes it more difficult to record reflected UV in particular. Manufacturers of sunscreen have used the techniques to demonstrate to consumers how to apply sunscreen safely and to highlight areas which are missed during the application process [4].

This chapter will survey a number of photographic techniques for visualising various medical conditions, primarily dermatological. Due to the nature of the subject, many of the techniques are shared with forensic photographers, who also need to record subjects such as burn and bite marks, and other conditions. A useful review of the techniques used in forensic work is given in Marsh [5].

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28.2 Techniques to Envision the Invisible

28.2.1 Grazed/Oblique Lighting

Changing the quality and direction of light falling upon a surface can greatly change the information within an image. By employing a low angle relative to the subject, usually around 15°, shallow surface texture can often be greatly enhanced.

It is probably best to use a single, relatively small light source, such as a small electronic flash gun (speedlight) or LED lamp from one side of the subject. By placing the light source to one side, there will invariably be a fall-off in the level of illumination from one side of the subject to the other. This may not be a problem, but can be improved if necessary by placing a reflective surface (white or silvered card works well) on the opposite side of the light source to bounce light back onto the subject and increase the brightness of the shadow areas, without destroying the effect of texture.

A useful way of achieving this, specifically for small areas, is to mount the flash gun to the end of the lens and direct it at an angle onto the subject. Both Nikon and Canon make macro flash units where small flash units can be mounted in this way and are a very convenient way of achieving consistent results. Using a 100mm macro lens or longer will enable a reasonable working distance between the camera and the subject.

Although some dermatological photography will be produced in black and white, most will be in colour, and it will be seen in the illustrations that the colours of the skin are different, due to the different makes of flash gun used for the photography. If colour is important, then it may be necessary to include a photographic 18% grey card in the image, or colour calibration chart such as the X-Rite Colour Checker Passport©. This can be used in conjunction with software such as Adobe Camera Raw© to white balance the image and give the correct colour of the subject (Figs. 28.1 and 28.2).

28.2.2 Polarised Lighting

The use of a polarised light technique can increase colour saturation and contrast by decreasing reflection or eliminating specular reflections from the subject, enabling the underlying colour to be captured. Three-dimensional (3D) whole body

Fig. 28.1 Accentuating surface texture. Positioning a small flash gun close to the lens at an oblique angle to the subject accentuates surface texture. Nikon SB-R200 flash attached to Nikon Micro-Nikkor 105mm lens, controlled by the R1commander

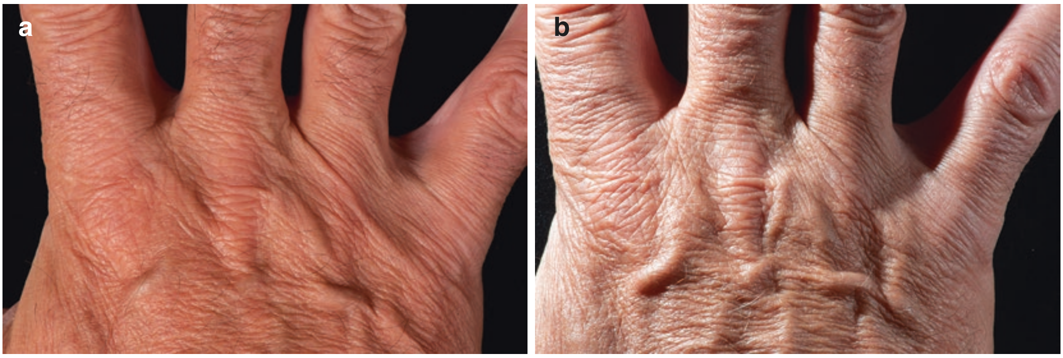

Fig. 28.2 (**a**, **b**) The effects of diffusion. The same area of the skin photographed with soft, diffuse light (left) and grazed lighting (right)

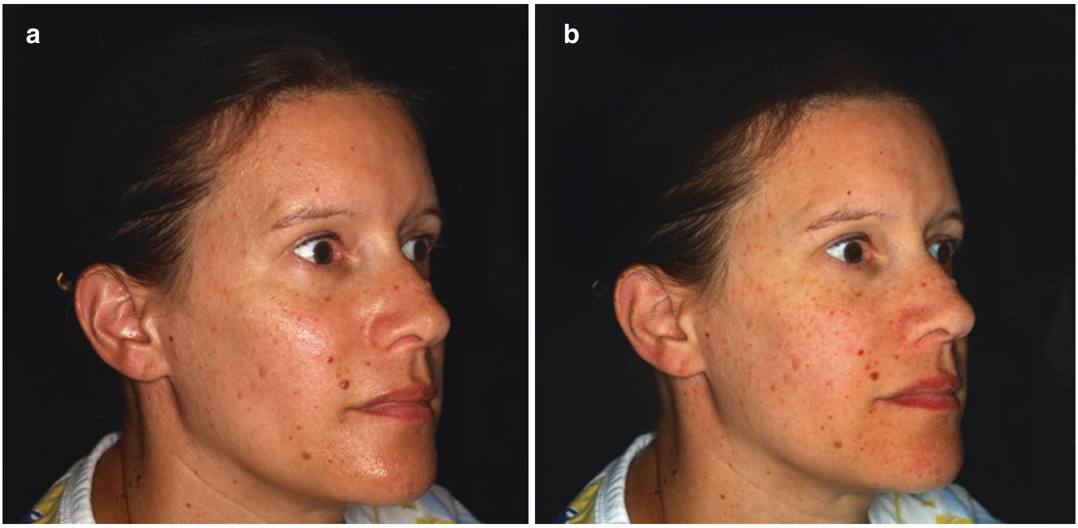

Fig. 28.3 (**a**, **b**) Normal and polarised light. Facial image in normal light and polarised light

polarised light photography has been used as a screening tool for the early detection and screening for melanoma skin cancer. Three-dimensional imaging is currently done using multiple cameras and light sources, to allow the whole body to be imaged at once and within a few seconds. By cross polarizing the light and camera, the colour of the skin can be shown without the specular highlights from surface reflection, enabling a more accurate capture of potential melanoma targets. This allows the creation of a 3D avatar of the patient and additional dermoscopy can be done to allow even higher-resolution imaging of potential melanoma targets when needed [6].

Polarised light techniques are also used extensively by forensic photographers [7], as well as the use of cross-polarised UV reflectance photography, and are discussed more fully in Chap. 28 (Fig. 28.3).

28.2.3 Ultraviolet and Infrared Photography: The Electromagnetic Spectrum

The visible light used by photographers to produce images is just one part of a range of ‘electromagnetic’ radiations.

The spectrum of visible light split by a prism, or seen in a rainbow, for example, begins at the violet or blue end of the spectrum and continues through green, yellow orange and red. Violet colours have a wavelength of approximately 400nm, green at around 550nm and red to approximately 700nm. The colours do not fall into neat discrete boxes, but instead form a continually changing spectrum, with the colours gradually blending into each other.

UV radiation has wavelengths shorter than 400nm down to around 10nm. It is usually divided into three regions according to its wavelength: UVA, UVB and UVC. The shorter the wavelength, the more harmful the radiation is to the human skin and other biological tissues.

Short-wavelength UVC (approximately 100–280nm) is the most damaging type of UV radiation. However, it is almost completely filtered by the ozone layer in the atmosphere and does not reach the earth’s surface. Wavelengths from 10 to 200nm are often referred to as vacuum UV.

Medium-wavelength UVB (approximately 280–315nm) is very biologically active but cannot penetrate beyond the superficial skin layers. It is responsible for delayed tanning and burning. In addition to these short-term effects, it enhances skin ageing and significantly promotes the development of skin cancer. Most solar UVB is filtered by the ozone layer in the atmosphere.

The relatively long-wavelength UVA (approximately 315–400nm) accounts for approximately

95% of the UV radiation reaching the Earth's surface. It can penetrate into the deeper layers of the skin and is responsible for the immediate tanning effect of the skin. It also contributes to skin ageing and wrinkling by damaging the collagen structure of the dermis. For a long time, it was thought that UVA could not cause any lasting damage, but recent studies strongly suggest that it may also accelerate the development of skin cancers. There is also increasing evidence that IR radiation (760–1440nm) may also be harmful to the skin, and various sunscreens now specify protection against it [e.g. 8].

For most photographic purposes, the UV wavelengths from 300 to 400nm will be most useful. Specialist quartz glass UV lenses will be needed to record images in UV wavelengths down to around 320nm, whilst normal glass lenses can, in some cases, record images using wavelengths down to around 350nm (although not all camera lenses are suitable for this type of imaging due to the coatings, adhesives and glass used in their construction which can all be very efficient UV blockers).

The IR section of the electromagnetic spectrum is generally regarded as being composed of three parts, near, middle and far infrared. For the purposes of photography, the near-infrared (NIR) wavelengths from around 700 to 1100nm are those that can be captured by conventional cameras and sensors. The middle- to far-infrared wavelengths (1100–2500nm) are known as shortwave infrared (SWIR) are those associated with specialist thermal imaging and night-vision cameras. IR-converted digital cameras are not sensitive to and cannot record wavelengths beyond around 1200nm.

As well as visible light, UV and IR, other examples of electromagnetic radiation include microwaves, (e.g. found in microwave cookers), X-rays and gamma rays, with wavelengths much shorter than UV, used in medical diagnostic imaging machines. Radiation beyond the IR includes heat and radio waves. A digital camera, converted to record IR cannot record heat (thermal radiation)—specific thermal imaging cameras are required to do that (Fig. 28.4).

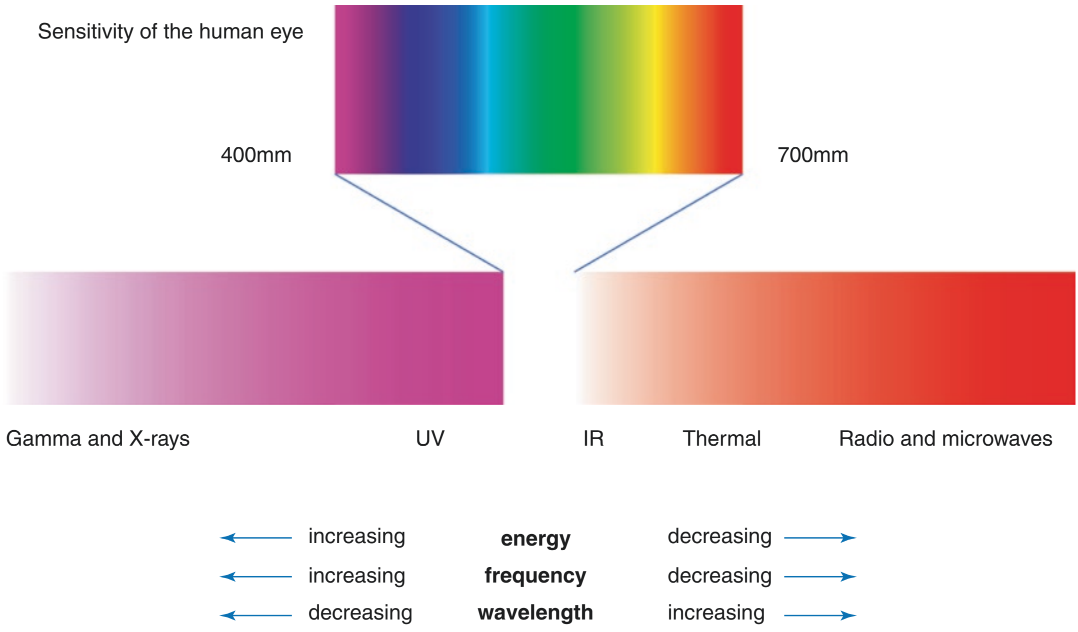

Fig. 28.4 The electromagnetic spectrum. The electromagnetic spectrum arranged according to frequency, energy and wavelength

28.2.4 Ultraviolet

There are two types of UV photography, reflected (UVR) and fluorescence (UVF). UV reflected photography is the recording of the UV reflected from a subject, excluding all other visible light as well as infrared wavelengths. UV wavelengths do not penetrate the surface of the skin, but instead tend to accentuate surface structures such as freckles.

UV fluorescence photography is concerned with the recording of the visible light emitted from a subject when it is illuminated, or 'excited' with a UV source.

28.2.4.1 UV Reflected Techniques

Photographing the UV reflected from a subject requires the removal of all visible and IR wavelengths, for which specialist equipment and filtration will be required.

For successful UV reflected photography, four elements are necessary (Fig. 28.5):

- An imaging sensor sensitive to UV wavelengths
- A lens transmitting useful amounts of UV (usually in the region of 360–400nm)
- A filter which absorbs all wavelengths other than UV (and possibly only a narrow range of UV)
- A light source rich in UV wavelengths

28.2.4.2 The Imaging Sensor

Monochrome photographic emulsions are naturally sensitive to UV wavelengths from around 230nm, peaking at 350–400nm [9], and can, therefore, be used to record UVR without modification. Digital sensors (CCD and CMOS devices) are also sensitive to UV (and IR), but most have a filter (sometimes called a 'hot mirror' filter) applied to the surface at the time of manufacture to absorb the UV and IR so that conventional photographs are the correct colour (i.e. without having an excess of UV and IR). For UVR photography, this filter can be removed (usually by a specialist conversion company) to allow UV wavelengths to reach the sensor. The sensor can then be either left unfiltered (usually being covered with a piece of plain glass for protection) so that it is sensitive to UV, visible and IR (when it is usually referred to as a 'full spectrum' conversion) or have a UV transmitting filter inserted over the sensor. A UV-only conversion will limit

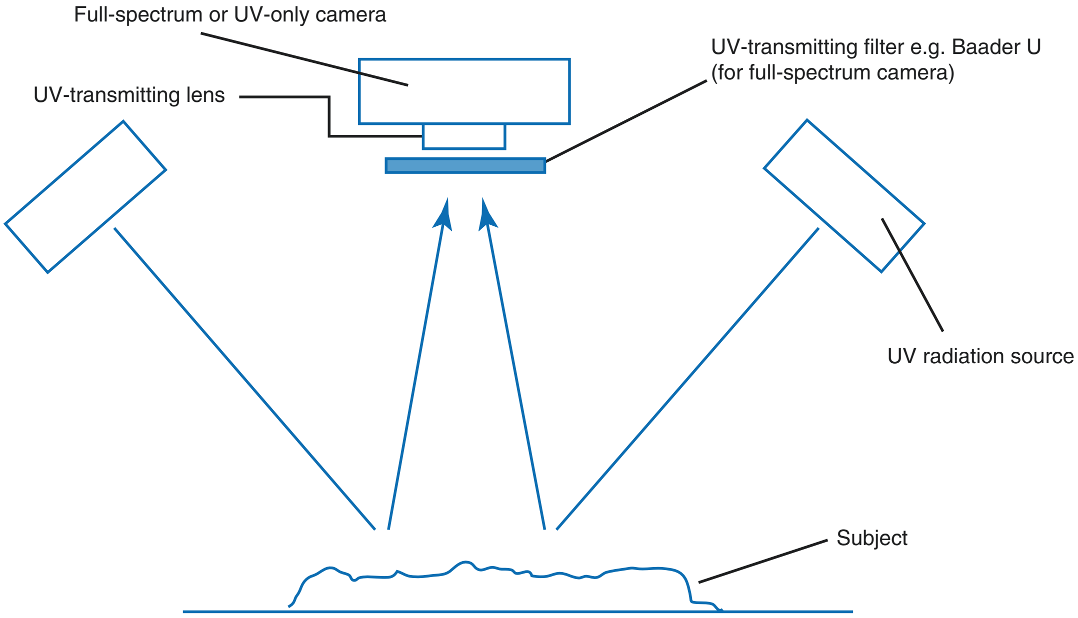

Fig. 28.5 The basic requirements for UV reflectance photography

the use of the camera to the characteristics of the internal filter used, and it will be necessary to get the specification of this filter from the conversion company. A full spectrum conversion will give a much more flexible option, allowing both UV and IR images to be recorded, as well as 'normal' visible light images (with an appropriate filter), but will require the use of filters on the camera lens, which may make the use of the camera viewfinder difficult or impossible. Some cameras have a 'live view' facility on the LCD screens on their rear face, which can sometimes be used to help with image composition and focusing when filters opaque in the visible spectra are being used.

It is also possible to remove the Bayer colour filter array from the front of the sensor to produce monochrome images. This operation increases the effective sensitivity of the sensor to UVA by about 6 times, or 2.5 photographic stops [10], and is a good solution for UV reflectance imaging if colour information is not required. It is however an extremely delicate and expensive procedure and is offered by Llewellyn Data Processing (LDP LLC) for example.

Whilst it is possible to carry out these conversions yourself, it is recommended to have the work carried out by a specialist company, who will have the necessary equipment, expertise and dust-free conditions to do it. They will also have the knowledge about whether the camera is suitable for conversion (some Nikon models, for example, have an internal infrared shutter monitor which will contaminate photos in a converted camera in which the internal UV/IR blocking filter has been removed).

Little quantitative work has been carried out on the conversion of sensors for UV (and IR) though two reviews included useful information [11, 12].

A list of recommended camera conversion companies is given in the Section 28.5 Sources for camera conversion.

One particular camera make has a 'user removable dust filter', containing the UV- and IR-absorbing material. Sigma camera models, including the Sd Quattro, have a **Foveon X3©** sensor, which differ fundamentally from the CCD and CMOS types in all other digital cameras. Tests have been carried out to determine the IR performance of this camera [13], but none has yet been carried out to determine UV performance.

28.2.4.3 Visible Light Control Image

It will often be necessary to record a visible light image of the subject alongside the UV image to enable comparison. This is possible with a 'full spectrum' converted camera by placing a 'hot mirror' filter (e.g. Schott S8612 or Kolari Hot Mirror) over the lens (effectively the same filter that was removed in the conversion). This absorbs UV and IR and transmits visible light onto the sensor. Colour balancing may be required through the use of a photographic grey card to ensure correct colour.

28.2.4.4 The Lens

Most optical glass (e.g. the crown glass used in windows) used in the construction of modern camera lenses has very poor UV transmission, transmitting virtually nothing below 350nm [9]. Also, most modern camera lenses are coated with a range of coatings to prevent flare, and absorb UV and IR wavelengths, unwanted in conventional photography.

28.2.4.5 Specialist UV Lenses

A lens specifically designed for UV transmission is ideally constructed from quartz (or fluorite) glass elements. Over the years, several camera and lens manufacturers have constructed special lenses, constructed mainly from quartz glass and calcium fluoride elements, specifically for transmitting UV. Some historic examples are:

- Nikon UV-Nikkor 105mm f/4.5
- Hasselblad UV-Sonnar 105mm f/4.3
- Pentax Ultra-Achromatic Takumar 85mm f/4.5

These are sadly long discontinued, and are generally rare, but can still occasionally be found, though always command very high prices.

Some quartz glass lenses designed for UV photography are still manufactured today though, including the Nikon Rayfact 105mm f/4.5 UV lens, a copy of the Nikon UV-Nikkor 105mm. It is distributed by Company Seven. Also currently available is the Jenoptik 60mm f4.5 APO macro lens, which has a good UV transmission down to approximately 320nm. These are still expensive though, possibly beyond the budget of many readers.

28.2.4.6 'Accidental' Lenses

There is a popularly held misconception that UV reflectance cannot be recorded using a normal glass lens, which probably explains why there is such a relatively small amount of UV reflectance photography being carried out today. There is no doubt that special purpose quartz glass lenses are best for UV reflectance photography and will have the advantage of achromatic correction in the UV (i.e. they bring two wavelengths to the same point of focus, thus having little or no focus shift when used for UV photography). They will also enable the recording of wavelengths further down into the UV, from around 365nm to 320nm, whilst most non-quartz lenses will restrict photography effectively to 365nm and above. Quartz lenses will also transmit far more UV, and will therefore be effectively several stops faster than a conventional glass lens when used for reflected UV photography [14].

There are, however, several other types of lenses which can be used as good alternatives to quartz glass models, often very successfully, for UV reflectance photography. Various types of lenses from devices such as fax machines, reprographic cameras, enlargers and various scientific instruments have been tested to see which ones transmit useful amounts of UV. There are several databases available on various forums on the internet listing 'accidental' lenses, i.e. those designed originally for another purpose, but found to be suitable for UV reflectance photography.

One particularly useful type of lens for UV reflectance photography, often readily available at a reasonable price, is that specifically designed for use with photographic enlargers. These lenses, although made of crown glass, generally have little in the way of UV-absorbing coatings on their elements, and come in a range of focal lengths. One of the specifications for an efficient and high-quality enlarging lens is for it to have a good blue light and UV transmission, appropriate for its use when exposing monochrome photographic papers, which are designed to be sensitive to UV radiation and blue light (and hence are 'safe' in red light in the darkroom). The wavelength transmitted by such lenses is usually limited to around 350nm. They can be found relatively cheaply on internet auction sites.

One particular range of enlarging lenses that has been found to work extremely well for UV reflectance work is the Nikon El-Nikkor, available in a range of focal lengths including 50, 63, 75, 80, 105 and 135mm. The ones found generally to work best are the oldest ones, with a metal body and scalloped focusing ring. In general, the later plastic-bodied versions have been found to not transmit as much UV as the older models, but are still worth trying. The corresponding authors' own 'standard' UV lenses are El-Nikkor 80mm f/4 and 105mm f/5.6 enlarging lenses, dating from around 1970, which were obtained through online auction sites for around £70 each. These are used with a full spectrum modified Nikon D300S camera, which has a crop factor of 1.6×, giving the lens an effective focal length of 128mm and 168mm, respectively. This gives a useful relatively long working distance from the camera to the subject, allowing enough space to arrange the various light sources around the subject. The 105mm is, conveniently, the same focal length as the 105mm Micro-Nikkor lens which is used for taking many of the visible light control images shot alongside the UV images for comparison. Other focal lengths which have shown to have particularly good UV transmission are the 63 and 80mm versions.

A Nikon technical brochure [15] gives the following spectral transmission figures for the El-Nikkor range of enlarging lenses:

- 50mm f/2.8 and f/4: 370–700nm
- 63mm f/3.5: 350–700nm
- 80mm f/4: 370–700nm
- 105mm f/4: 380–700nm

(Later brochures from the 1980s give a more general figure of 380–700nm for later models of these lenses).

Fig. 28.6 Set up for UV reflected photography. Full spectrum converted Nikon D300 camera with Baader U-filter, mounted onto a gelatin filter hold (Nikon AF-1). There would normally be a lens hood mounted on the front of the filter

According to this technical sheet, the 'El Nikkor lenses are corrected against chromatic aberrations, not only for visible light, but also for near UV rays, so that the image formed of the visible light exactly coincides with that of the UV ray, and focusing can be adjusted perfectly …' [15]

It goes on to say that 'Another important point is that special type of glass is not used for making these lenses as such glasses are apt to absorb UV rays, resulting in the production of an enlarging lens with deficient brightness. In addition, an anti-reflection coating for the wavelength 400nm is applied to increase the transmission of UV rays. Thus, the lenses perform uniform spectral transmission covering the range from visible light to UV ray'(sic).

The websites www.macrolenses.de and www.ultravioletphotography.com have extensive database of ordinary glass lenses found to be useful for UV reflected photography.

These enlarging lenses usually have a 39mm Leica screw thread, and an adapter will be required to enable them to be fitted onto a digital camera. They do not have a helicoid focusing thread built into them, so will need to be mounted onto an extension bellows unit or extension tubes to enable focusing. One particularly useful type of extension tube has a helicoid focusing thread built into it to enable focusing (Fig. 28.6).

28.2.4.7 The Filter

A filter will be required to absorb all visible and IR wavelengths and just transmit UV wavelengths. Traditionally used UV-transmitting filters, such as the Kodak 18A 'Wood's Glass', B + W 403, Schott UG1 and Schott UG11, transmitted high levels of UV but also a significant quantity of IR, making them unsuitable for use with a full spectrum converted camera. Perhaps the most widely used UV-transmitting filter currently is the Baader Planetarium Ultraviolet Venus filter (more commonly known as the Baader U), used by astronomers for viewing the strongly UV reflective clouds around the planet Venus (and sometimes referred to as the 'Venus filter') (Fig. 28.7).

The Baader U-filter transmits wavelengths from 320 to 390nm, with 85% transmission at 350nm. It completely absorbs visible light and IR wavelengths. It is constructed with a disc of high-grade Schott UG-11 optical filter glass, precisely ground to be optically flat. The glass then undergoes a vacuum deposition coating process where 40 layers of micron-thin coatings of various elements are applied on top of each other, in a precise order and specific thickness.

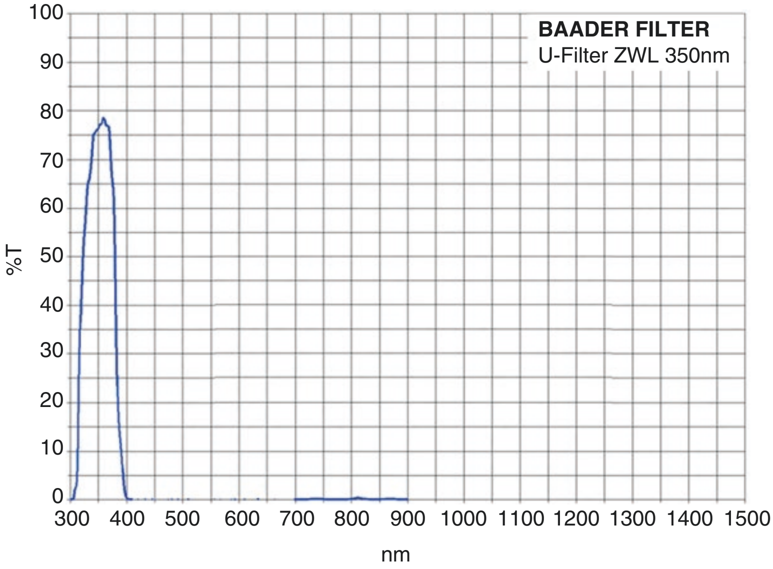

Fig. 28.7 Spectral transmission curve for the 'Baader U' UV-transmitting filter

The Baader U-filter is only available in either 1.25″ (31.75mm) or 2″ (48mm) diameter sizes, requiring the use of filter stepping rings to fit it onto most photographic and enlarger lenses.

Unless you are using a UV-only conversion, focusing by looking through the camera viewfinder will be impossible when the filter is in place. A useful method of attaching the filter is via a gelatin filter holder, such as the Nikon AF-1. This has a 60mm front filter thread designed to attach a lens hood, into which the filter is inserted. The filter can be quickly lowered for focusing, and then raised into position for shooting the image.

The Baader U-filter has a different colour on each side (dichroic), yellow and magenta. Because it is designed for the eyepiece of a telescope, the threaded side would face the source of light, which is the opposite of how it would be when fitted to the front of a photographic lens. For this reason, some authors [e.g. 10] recommend reversing the Baader U-filter in its mount, so that the magenta side (the dielectric coating) of the glass faces forward, probably as a precaution against internal flare from the highly reflective surface. This is easily achieved by carefully unscrewing the retaining ring which holds the filter in place in the mount, reversing the filter, and replacing the ring. Take care not to overtighten the ring and possible alter the optical flatness of the filter. It is also a good idea to use a lens hood on the front of the filter, to minimise the risk of flare.

28.2.4.8 Focus Shift

The focal length of a lens is, strictly, dependent on the wavelength of light passing through it, but the same wavelengths may be focused at different distances by different glass materials used in the lens. Older camera lenses were achromatic, i.e. they brought two wavelengths to a common point of focus, whilst later, higher-quality lenses were apochromatic, i.e. they brought three wavelengths of visible light to a common point of focus. Both UV and IR wavelengths are brought to a different point of focus to visible light, and images shot in UV (and IR) may well be out of focus. Older lenses for analogue cameras used to have an IR focusing spot engraved on the barrel. When having a camera converted to shoot UV or IR, this shift can be compensated for by having the camera calibrated at the time of conversion. If you have a full spectrum camera, you need to specify which wavelength you wish it to be calibrated for, either UV or IR.

It is relatively easy to determine the focus shift for a specific lens when used in UV [16]. Place a millimetre scale at 45° to the lens axis (several proprietary lens calibration systems are available from some of the companies listed in the resources section), and focus the lens at its midpoint. Shoot two images, one in visible light and one in UV. The amount of shift can be estimated visually. Strictly, the resulting figures should be multiplied by cos 45° (= 0.707) to give an actual figure in millimetres, though this probably won't be necessary if the lens is stopped down by one or two stops to increase depth of field). The focus shift will be at its greatest when the lens is used for close-up or macro photography.

Even with a converted camera which has been calibrated to give its correct focus in UV, it is probably worth stopping the lens down by two or three stops if possible, to increase depth of field and use the optimum resolution of the lens.

28.2.4.9 The UV Source

There are several light sources containing useful amounts of UV for UVR photography, including daylight, tungsten, LED and xenon tube electronic flash. Daylight is of course highly variable, in both amount and UV content. It varies with cloud cover and also altitude. This makes it unsuitable for producing consistent imagery. Tungsten is hot and would be uncomfortable for patients, whilst LED sources may not emit sufficient quantities of UV for practical photography of patients.

The most convenient, consistent and accessible source of UV for dermatological use is the xenon-based electronic flash unit. Xenon tubes emit good quantities of UV as well as visible and IR wavelengths [8]. Because normal photography does not need the UV component, this is usually filtered out by the manufacture, either by placing a plastic UV-absorbing window over the flash tube or by coating the flash tube with a UV-absorbing coating. The plastic window in front of the flash tube can usually be removed (great care must be taken when dismantling flash guns to remove the plastic windows as flash guns, even if they have not been used for some time, may retain a large electrical charge in the capacitor). This modification should be carried out by a qualified electrician and allow the UV content of the tube to reach the subject. It is also possible to chemically remove the coating from a flash tube [17].

28.2.4.10 Harmonisation Diagram

It is useful, when assembling a collection of components such as this for a particular task, to map their characteristics onto one graph to make sure they coincide, or harmonise (Fig. 28.8).

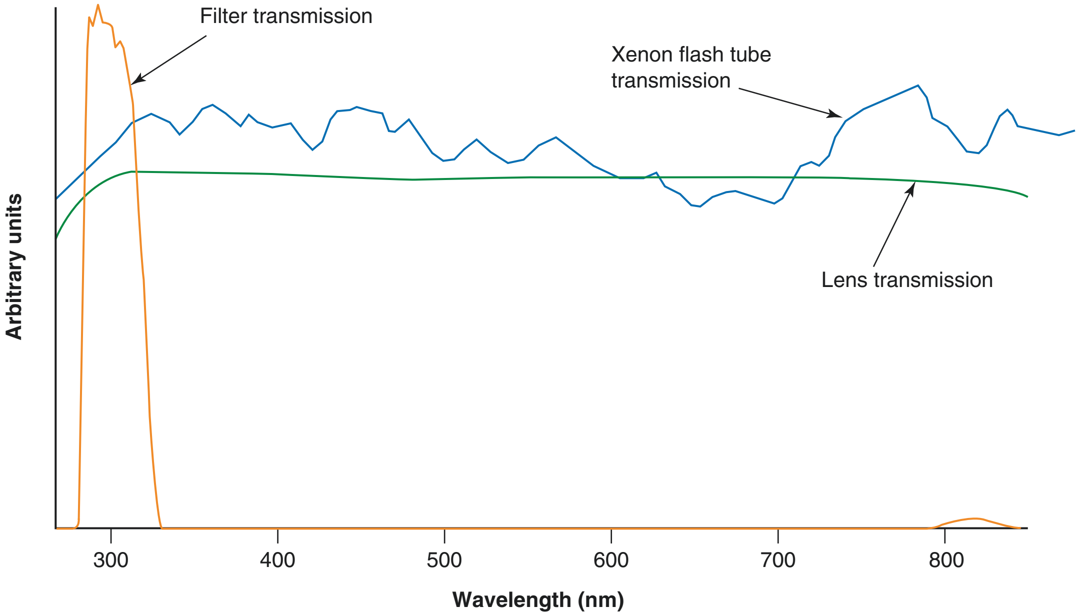

Fig. 28.8 Harmonisation diagram for UV-transmitting filter, unfiltered xenon flash tube and UV-transmitting lens

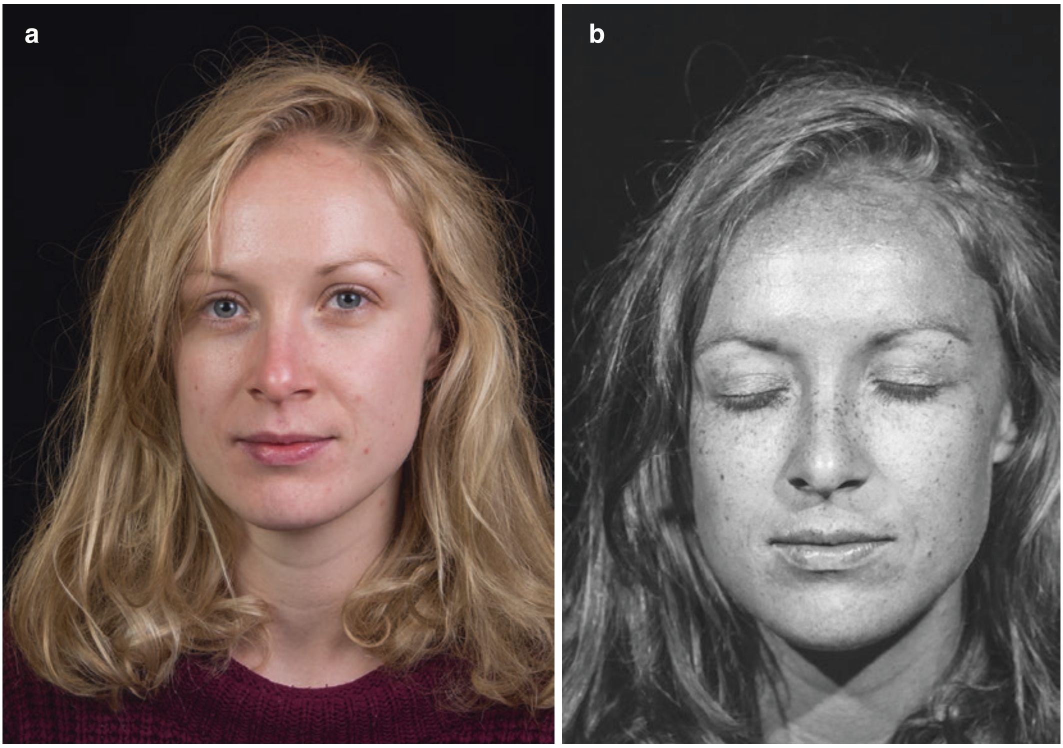

Fig. 28.9 (**a**, **b**) Visible light and reflected UV. Facial image in visible light and UV reflected radiation. Nikon D330 'full spectrum' conversion camera, El-Nikkor 105mm lens and Baader U-filter. Lighting: 2× Metz 45CL1 flash guns with UV/IR-absorbing window removed. 1/60th second at f/8. Note, the model was asked to shut her eyes for the exposure, to minimise hazard of UV exposure to the eyes. Also note double shadows under the chin

With a harmonisation diagram, the researcher will be able to determine whether the light source produces enough light to pass through the filter and lens and to be able to be detected by the camera. However, accurate data may not always be available for all the components. It does however emphasise the need to assess all components within the image capture process to ensure that they will efficiently work together.

28.2.4.11 Technique

For most UVR photography, particularly of dermatological subjects, flat, even lighting would be most appropriate, so that shadows caused by uneven directional lighting do not interfere with UV-revealed information. Two equally powered lights are preferred, equidistant to the subject, though this may lead to double shadows, as shown in the illustration (Fig. 28.9).

28.2.5 UV Fluorescence

UV fluorescence is currently widely used in medicine for dry skin assessment and also more recently for bacterial porphyrin imaging. It can also be used to show various dermatological conditions such as Tinea capitis, for example—a Wood's lamp is commonly used in clinics to visually detect this condition. A traditional Wood's lamp is a low-output mercury arc covered by a Wood filter (barium silicate and 9% nickel oxide) and emits wavelength 320–450nm (peak 365nm). The lamp was invented in 1903 by a Baltimore physicist, Robert W. Wood.

Modern black light sources may be specially designed BLB fluorescent lamps, mercury-vapour lamps, light-emitting diodes or incandescent lamps. Fluorescent black light tubes have a dark blue filter coating on the tube, which filters out most visible light. There are several models

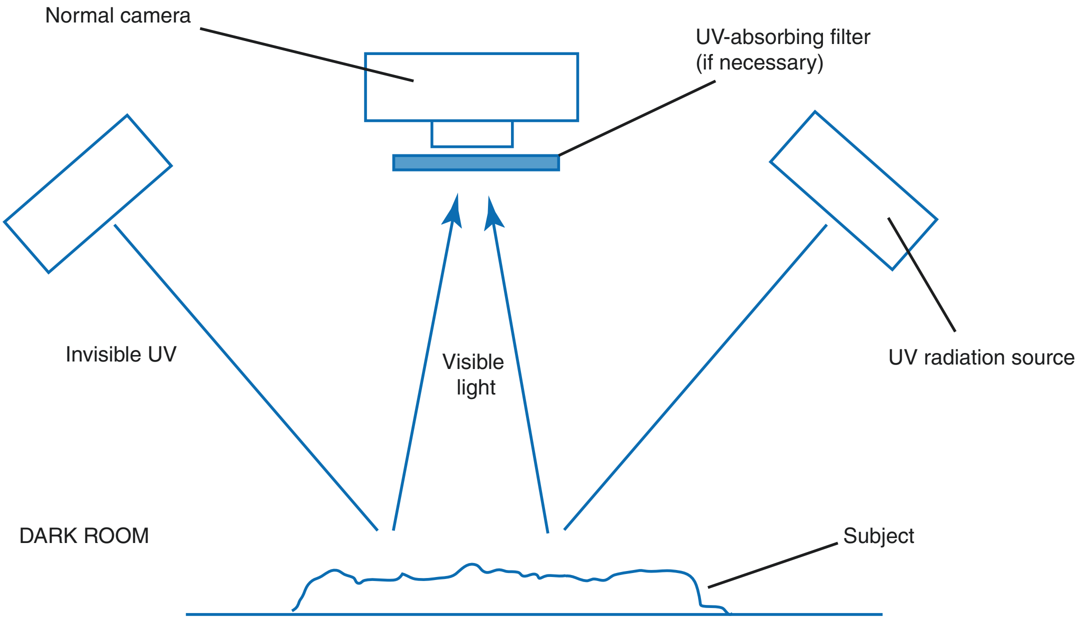

Fig. 28.10 The basic requirements for UV fluorescence photography. This needs to be carried out in a darkened room

with varying properties. The medical Wood's lamp may include:

- A variety of phosphors with different peak emission
- Magnifying lens
- White light
- Black drape to exclude light

The technique is also used in hygiene training, showing the effectiveness of handwashing, using special UV fluorescing gels such as GloGerm. The technique is also used extensively by geologists for helping with the identification of minerals by the fluorescent colour emitted.

A normal unconverted camera with normal lens can be used for fluorescence imaging as it is the visible light emitted from a subject when 'excited' by a UV source that is to be recorded. The subject will need to be in a dark room and illuminated with a UV source. This might be an LED torch emitting UV, or perhaps a flash gun where the tube is covered with a UV-transmitting filter. Some of the camera conversion companies market modified UV flash guns (Fig. 28.10).

LED UV torches are now powerful, relatively inexpensive and popular with UV photographers. Models with good reputations include the Convoy S2+UV and the MTE S303, which use Nichia Power 365nm LED chips. It must be remembered that whenever UV light is being shone onto a subject that adequate eye protection must be used in the form of UV-blocking safety glasses, as discussed further below.

For specific applications, particularly when used for forensic work, UV sources of very specific wavelengths can be used to highlight subjects such as fingerprints, and lasers and other sources are available from specialist forensic suppliers for this purpose.

It is worth checking that the UV source in use is not emitting any visible light. A simple test is to shine the source onto a metallic object such as ball bearing or coin. If the object cannot be seen, then the UV source is pure. If the object can be seen, it means that there is some visible light leakage from the UV source. This can be filtered with a visible light filter such as a Hoya U-330 or U-340 filter.

The photography will need to be carried out in a completely dark room so that only the UV fluo-

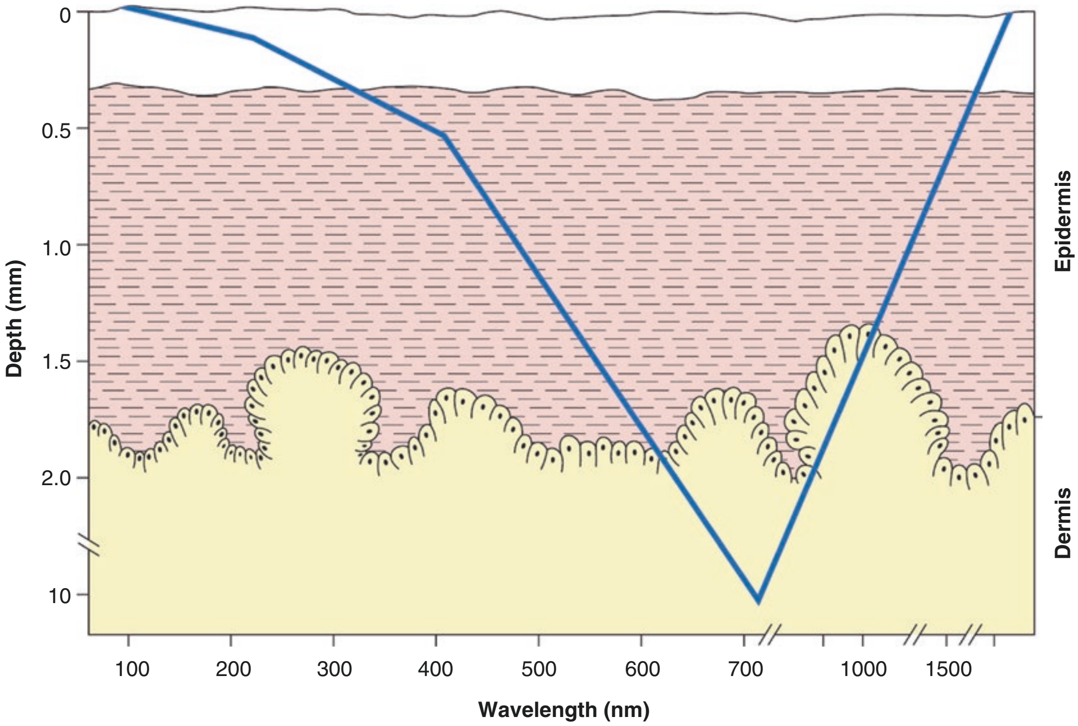

Fig. 28.11 Penetration of different wavelengths into the human skin. (After Williams, 1988)

rescence is recorded. Focusing will need to be carried out with the aid of visible light, which is then extinguished for the UVF record. It will be necessary for the subject to remain completely still to ensure that focus remains constant. If you are using a relatively small source in relation to the subject, it may be necessary to use a 'light painting' technique, whereby the source is moved during a relatively long exposure, often 10 s or more, effectively painting it with light. This will be more appropriate for static specimens.

28.2.5.1 Safety Notice

All UV wavelengths can cause permanent damage to the eyes or skin. Continuous sources in particular can cause skin burns or severe conjunctivitis, either to the photographer or your subject if you are shooting portraits. Conjunctivitis and skin erythema may only appear some hours after exposure to UV, so there is no warning that you are exceeding a 'safe dose'. It is very important, if using UV sources frequently, that you take great care not to look directly at them and wear good-quality protective glasses. Patients too should be given glasses to wear if the source is to be used anywhere near their eyes. These should be of the 'wraparound design' and absorb 100% of UV radiation.

28.2.6 Infrared

IR wavelengths penetrate the skin more than UV and can be used to show subcutaneous venous patterns and other skin anomalies. One particular device using IR radiation is the VeinViewer by Christie Medical Holdings. This device projects near IR onto the skin. Haemoglobin in the blood absorbs the IR, whilst surrounding tissues reflect it, producing a high contrast image which can help clinicians accurately find bifurcations or valves, for example (Figs. 28.11 and 28.12).

Although long out of print, the Kodak publication *Medical Infrared Photography* [18] is prob-

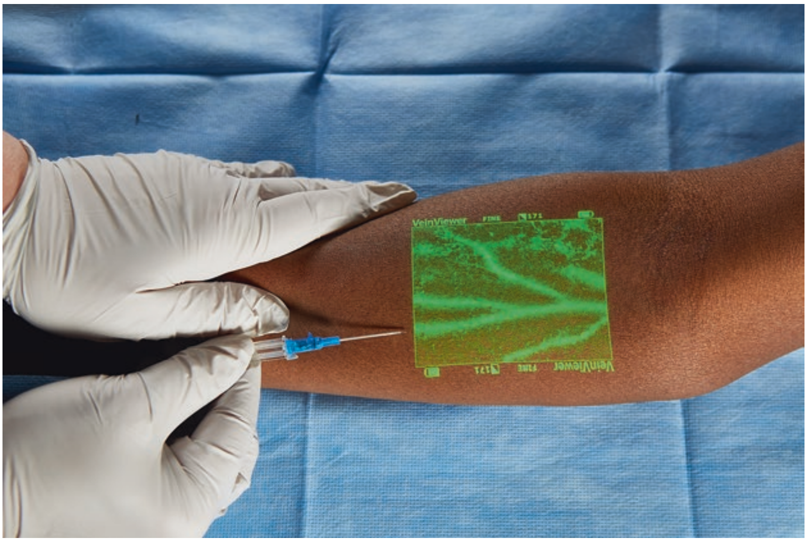

Fig. 28.12 The VeinViewer projects an image in real time of the veins beneath the skin to enable clinicians to position catheters accurately into veins. (Image credit: Christie Medical Holdings)

ably still the best account of the use of IR photography in medicine (albeit with analogue film).

For IR recording with a digital camera, the sensor will need to be converted, either to IR only or full spectrum. More on camera conversion can be found in the section on UV reflected photography.

28.2.6.1 Lens

Virtually any camera lens can be used for IR photography, though some exhibit distinct 'hot spots' in the centre of the image when used for the purpose. It is often not clear why some lenses do this and others not. Various databases can be found on the internet indicating which lenses have been found to be satisfactory for IR recording (see web links 28.4).

28.2.6.2 Filter

When using a 'full spectrum converted camera', a filter will be required over the lens to absorb all visible light (and UV) and just transmit IR wavelengths. Several are available, relatively cheaply, and may be found in a range of transmissions, for example, 720, 800 and 950nm. Examples include the Hoya R72 and B + W 093 filters (Fig. 28.13).

28.2.6.3 Light Source

Many light sources contain good levels of IR, including daylight, incandescent, LED and electronic flash. Of these, electronic flash will be the most convenient and consistent (Fig. 28.14).

28.2.6.4 Focusing with UV and IR Wavelengths

Conventional camera lenses are designed to bring all wavelengths of light, from 400 to 700nm to a single point of focus (apochromatic). UV and IR wavelengths will be brought to a different point of focus (older lenses often had an IR focus mark engraved on the lens barrel), and it may be necessary to carry out tests to determine the amount and direction of focus shift—a simple scale placed at an angle of 45°. Focus on the centre, and shoot images. The resulting images will show whether there is a focus shift and if it is in front of or behind the main point of focus.

As with UV reflectance photography, try to use even lighting on the subject, so that shadows do not interfere with surface detail. Two lights of equal power and placed at an angle of 45° to the subject will provide even lighting.

28.3 Conclusion

Various photographic techniques such as UV, IR, fluorescence and polarised imaging can provide images of skin form and function which are difficult or impossible to observe with standard visible light photography. Through the correct choice and com-

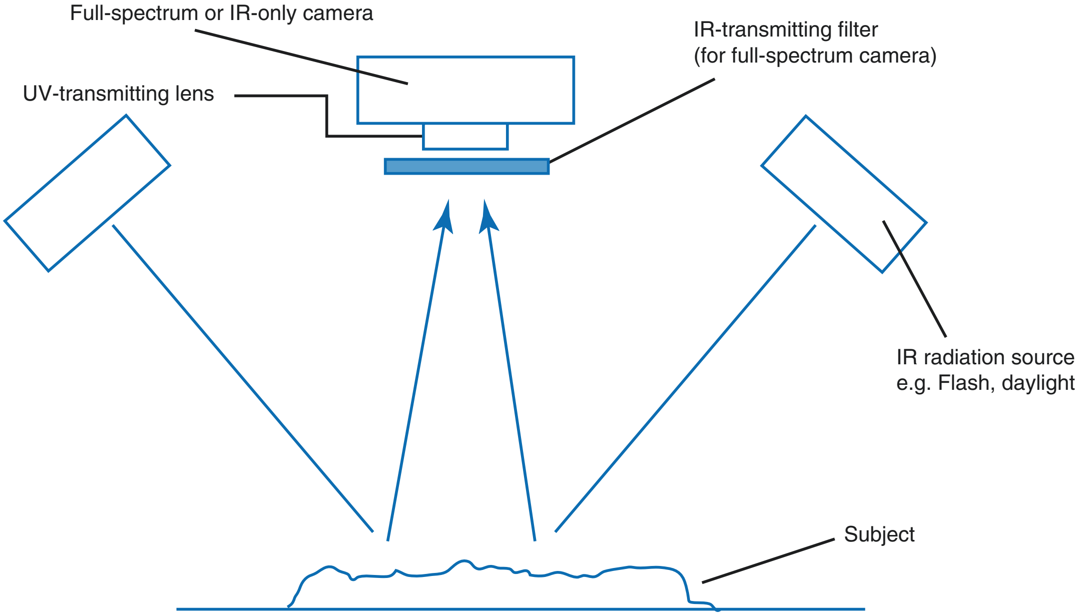

Fig. 28.13 The basic requirements for IR photography

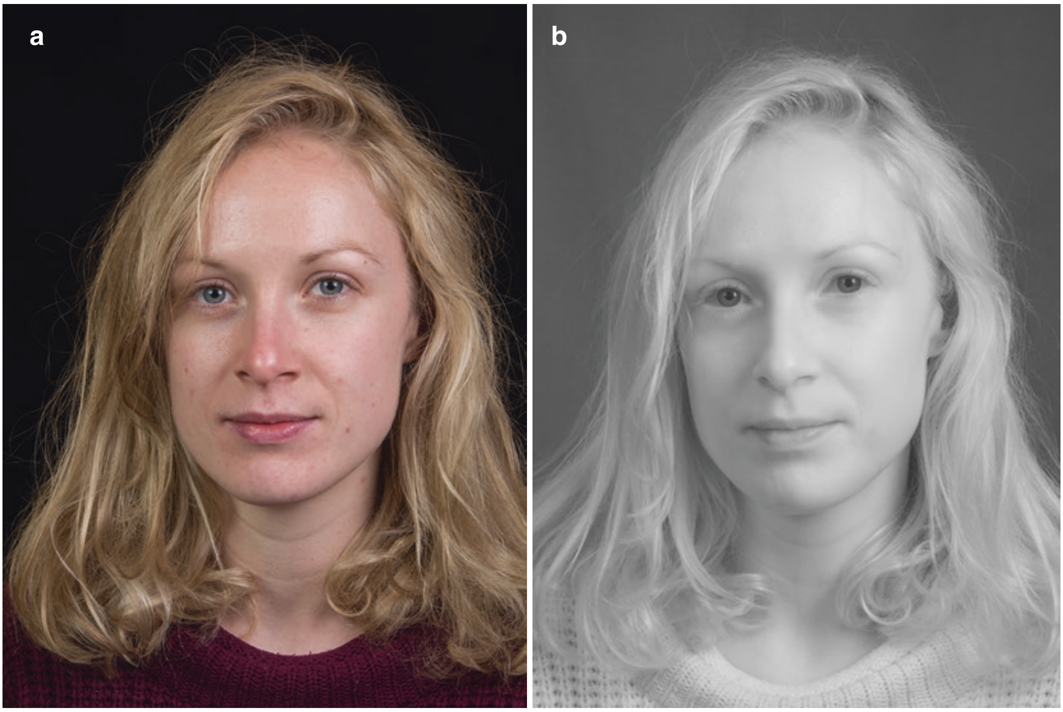

Fig. 28.14 (**a**, **b**) Normal and IR photography. Portrait in visible lighting and IR. IR produces a smooth, virtually blemish-free image, which can penetrate the surface to show subcutaneous blood vessels. Full spectrum conversion Nikon D300 with 105mm Micro-Nikkor f/2.8 lens and 720nm filter. 2× Metz 45CL1 flash guns with UV/IR-absorbing window removed

bination of camera, lens, lighting and filter, a wide range of skin conditions can be imaged by the researcher. However it is essential to consider all aspects of the imaging process, especially when dealing with non-visible light imaging, to ensure that reliable and consistent images can be captured.

28.4 Useful Web Links

www.ultravioletphotography.com—a forum for UV photographers, looking primarily at technical issues, with extensive databases of lenses and filters.

http://photographyoftheinvisibleworld.blogspot.com—A blog by Dr. Klaus Schmitt, with an extensive database of UV transmitting lenses.

28.5 Sources for Camera Conversion

Advanced Camera Services: http://advancedcameraservices.co.uk/

Lifepixel: https://www.lifepixel.com/. Web site contains many useful tutorials, and information on IR compatible lenses.

Kolari Vision: https://kolarivision.com. A useful source of reference, and retailer of various filters.

Llewellyn Data Processing (LDP LLC), NJ, USA. (MaxMax). https://maxmax.com/. A conversion company offering a "debayering" service for sensors, as well as UV and IR conversions.

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29

Beyond the Visible: UV, IR and Fluorescence Imaging of the Skin

Jonathan M. Crowther and Adrian Davies

Contents

29.1 Introduction

Our world is typically an abundance of colour, from which we derive a vast amount of information about it. Even within the range of human vision, there are some individuals who can see only in black and white (achromatopsia) [1] and, at the other end of the spectrum, some (tetrachromats) who see millions of colours [2]. Despite these apparent differences in how human eyes operate, we are still only sensitive to a relatively narrow range of wavelengths between approximately 390 and 720 nm [3]. Standard visible light imaging of the skin can provide a wide range of information about skin condition, such as redness and erythema, overall appearance and skin tone [4]. However as we perceive the world, we often forget that even from the sun there is a much wider range of wavelengths around us which our eyes are not sensitive to, the majority of which is between 300 nm and approximately 3000 nm [5]. At wavelengths shorter than we can perceive there is ultraviolet (UV) light, and at longer wavelengths than we can see is infrared (IR) radiation. These shorter and longer wavelengths interact with the skin differently to visible light and can provide additional information impossible to obtain with normal visible light imaging. However, imaging in these regions does come with its own complexities, such as the need for specialist camera equipment, lenses, lighting and subject handling. Given the complexity of UV, IR and fluorescence imaging, the reader may be wondering why they should bother with these

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techniques and what value they can be to the skin researcher.

While they will be covered in greater detail later in their respective sections in the chapter along with fluorescence imaging, as an introductory example, photographs of the skin under UV, IR and normal visible light are shown in Fig. 29.1 to highlight the key differences, along with the transmission spectra of the filters used to acquire the images (Fig. 29.1).

Visible light imaging of the subject in sunlight using a standard camera (Fig. 29.1a) produces a typical photograph, showing the skin tone and colour. White and dark hairs can be seen in the beard and scalp areas, and it is possible to faintly make out darker pigmented areas on the skin such as moles. By imaging the skin with UV light or IR radiation, the skin takes on a very different appearance to that of a visible light photograph. For instance, in the reflected UV light image, the skin looks to be a darker tone than it would under visible light (Fig. 29.1b). This is because the absorption of light by melanin rises as the wavelength shortens resulting in stronger absorption of the UV wavelengths compared to visible light [6]. UV light also accentuates surface texture of the skin, making lines and wrinkles seem more prominent. The subject's glasses now appear black, as they have a UV protective coating on them which absorbs UV light and prevents it from reaching the eyes. Conversely under IR light, the skin takes on an almost translucent tone

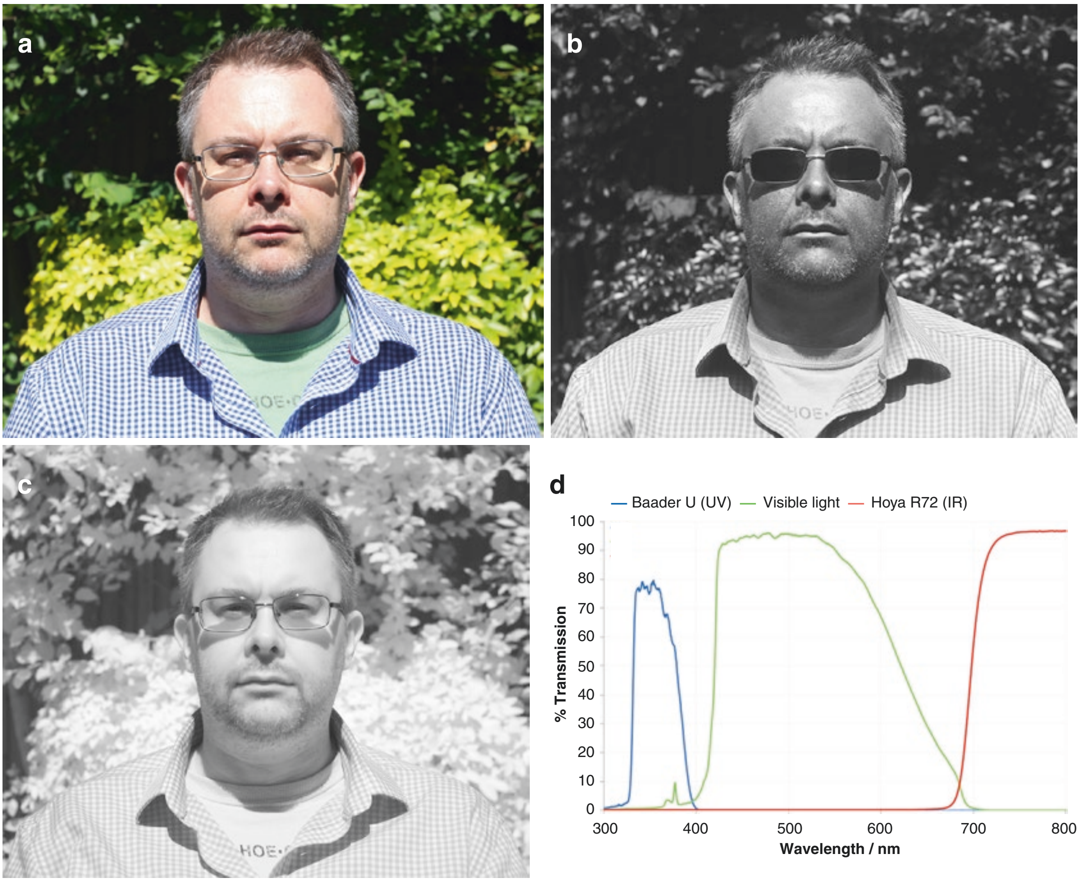

Fig. 29.1 Facial photographs taken with (**a**) visible, (**b**) UV and (**c**) IR light and (**d**) transmission spectra of filters used in taking the photographs

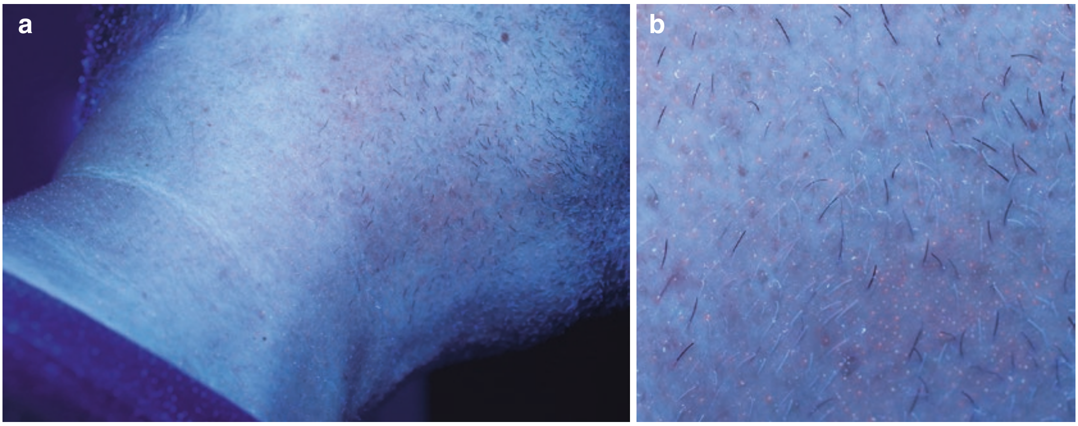

Fig. 29.2 UV-induced visible fluorescence of the skin showing the side of the neck and face: (**a**) full area and (**b**) close-up of cheek area

and looks lighter than under visible light (Fig. 29.1c). IR light of the wavelengths this camera was sensitive to is poorly absorbed by the skin, and can pass further in, scattering as it goes, blurring the internal features and smoothing the appearance of wrinkles and texture. The melanin offers relatively little absorbance to IR so moles and freckles are no longer visible. The UV and IR images are presented as monochrome images and were taken on a standard single-lens reflex (SLR) camera converted to monochrome, multispectral imaging. The images in Fig. 29.1a–c were all taken with the same 85 mm f4.5 Asahi Ultra Achromatic Takumar lens, with a Baader U filter for the UV image and a Hoya R72 filter for the IR image, and as will be discussed later, the choice of lens and filter as well as camera and light source are all vital to consider when imaging in UV and IR. The transmission spectra of the filters used for the images are shown in Fig. 29.1d. The filter transmission curve for the visible light image is derived from the filters from the front of the camera sensor and shows a typical drop in transmission towards the red end of the visible spectrum. The camera corrects this as it creates the image by boosting the level of red, to produce a final image which is correctly colour balanced.

The interaction of light with the skin is a complex process and a number of things can happen; it can be reflected either from the surface of the stratum corneum (SC) or from the interface between different layers within the skin, it can be absorbed, or it can also induce fluorescence—where the incoming light interacts with specific chemical entities within the skin and is re-emitted with a longer wavelength. Examples of UV-induced fluorescence of the skin are given in Fig. 29.2.

Fluorescence imaging (and more precisely UV-induced visible light fluorescence, in the case of Fig. 29.2) highlights drier skin areas as being lighter in colour and also produces a varying spectrum of colours from bacteria-rich areas such as within the pores and around the nose and forehead, which will be discussed further later in the chapter. This image was taken with a standard SLR camera and lens but with a flashlight modified to produce UVA light and block visible light.

This chapter will discuss some of the background to and practical aspects of the uses of UV, IR and fluorescence imaging of the skin and demonstrate how these techniques have been used to observe aspects of the skin and topical skin treatments which are not possible to visualize using standard visual light imaging.

29.2 Ultraviolet (UV) Imaging of the Skin

UV reflectance photography is where incoming UV light is reflected from the skin and then captured by the camera to make the image. It has been used widely in a variety of research fields

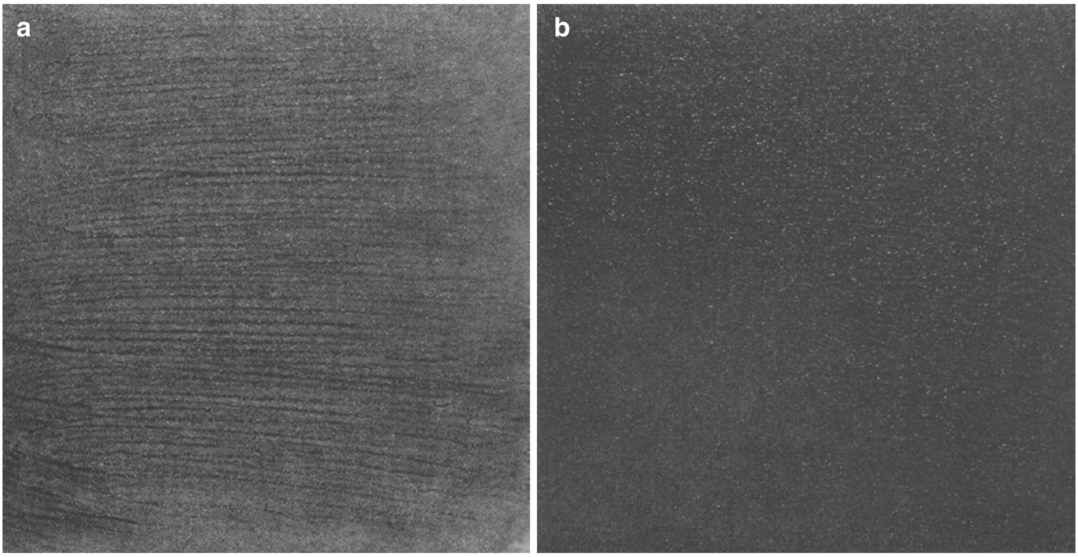

Fig. 29.3 Cross-polarized UV reflectance photographs of (**a**) 'bad' spreading product and (**b**) 'good' spreading product

including forensics [7–9] and skin imaging [10–16]. This is different to UV-induced fluorescence, where the incoming UV light results in the emission of visible or IR light, which is then subsequently photographed and will be covered elsewhere in this chapter. The UV imaging being discussed here has been done using UVA. UVB is more damaging to the skin, and as standard commercial cameras have virtually no sensitivity below 300 nm, even after removal of the Bayer filter UVB imaging has much less direct applicability to skin research with standard photographic equipment.

UV-related skin damage is a widespread issue with over 130,000 new cases of skin cancer diagnosed each year in the United Kingdom alone, in which UV radiation is attributed as the main preventable cause [17]. As such, formulating efficacious and protective sunscreen products is vital for both the consumer and pharmaceutical markets.

With the Sun Protection Factor (SPF) scale being logarithmic, as higher and higher numbers are attained, the amount of UV being absorbed before it reaches the skin gets closer and closer to 100%, making testing for the improvements offered by higher grades more and more difficult. Some correlations do exist between in vitro and in vivo SPF calculations; however it is far from a perfect relationship [6]. While the levels of sunscreen ingredients present will obviously have an impact on the overall protection capability of the product when applied to the skin, an area which is often overlooked is the chassis or formulation from which these ingredients are being delivered and the impact the chassis itself has on how the sunscreens spread and move onto the skin once applied [18]. The spread of the sunscreen ingredients will have a dramatic impact on the overall protection offered by the film, as areas of the applied film where the layer is thinner will more readily allow an increased level of UV to penetrate and damage the skin [19–21].

One key issue with using UV reflectance photography has been the shine which occurs when intense directional light is reflected from topically applied cream films resulting in a bright specular reflection. In order to minimize shine in visible light photographs, cross-polarization can be used, in which the light source and camera lenses have polarizers mounted on them at 90° to each other, thereby eliminating specular shine and revealing structures deeper inside the skin [22, 23]. While this process is well established for visible light photography, it has only been recently reported for UV imaging of sunscreens for topical formulations or for other applications in UV digital reflectance imaging [24]. By using cross-polarized UV reflectance photography, the difference between a 'good' and 'bad' spreading product can be seen in Fig. 29.3.

The sunscreen films in Fig. 29.3 look black as they are absorbing the UV light and preventing it from reaching the camera. The 'bad' spreading product in Fig. 29.3a has visible streaks in it from the spreading process. The light areas in the streaks are where the film is thinner and as such can absorb less of the incoming UV light. The 'good' spreading product shows a much more even finish with no obvious streaks from the application process. This would result in a more even finish and more consistent sun protection behaviour.

One drawback with cross-polarization is the reduction in the amount of light reaching the camera. The polarizers themselves absorb a substantial amount of light. With visible light photography, this isn't a problem as the camera sensors are sensitive enough in that part of the spectrum; however for UV imaging, this is a problem due to the lower sensitivity of the sensors to wavelengths below 400 nm. As such it is only recently with the advent of cameras with low noise at high ISO settings that have allowed cross-polarized UV imaging to be developed.

Capturing accurate UV reflectance photographs of the distribution of sunscreens during spreading can provide insight into their potential behaviour for sun protection, including areas which are often missed during application such as around the eye [25]. There is a strong correlation between effective in vivo SPF and thickness of the applied sunscreen film [19–21, 26, 27]. It therefore follows that thinner areas in an applied sunscreen film will let more UV light through, and as a result the skin will have a greater propensity towards developing erythema on exposure to UV light. As a result, the presence of these thinner layers will lower the effective SPF capability of the product. The spreadability of a product would also be expected to impact effective SPF—products which are easy to spread would create a more even film resulting in a higher SPF [28]. It is crucial, therefore, to develop products which have both the ability to block or absorb the UV and also are easily applied to the skin to promote usage compliance by the product user and to form an even layer across the skin.

Choice of imaging equipment is crucial to capturing UV reflectance photographs. Camera sensitivity to UV is low, and this is further reduced by the presence of the Bayer filter on the front of the sensor. Removal of the Bayer filter also increases sensitivity to UVA by up to around eight times depending on the specific wavelengths being imaged [29] and as such is an ideal modification for UV imaging if colour information is not required. It is however an extremely delicate and difficult procedure and is offered commercially by Llewellyn Data Processing LLP, NJ, USA. Some monochrome cameras are available commercially for research applications, but these are often much lower resolution than standard single-lens reflex systems and are not as user-friendly. As a simpler approach, removing the UV/IR filter in front of the sensor will enable the camera to be used for imaging in UV, visible or IR by placing suitable filters in front of the lens, albeit with less sensitivity to UV than a monochrome conversion. This may seem like an ideal route for a researcher; however it should be kept in mind that UV transmitting filters block visible light and therefore make it impossible to observe the subject through the viewfinder of the camera. This can be a complicating factor when dealing with imaging in a clinical setting and as such placing the UV conversion filter directly in front of the sensor to produce a dedicated UV camera but where the subject can still be seen through the viewfinder can be the preferred route.

The choice of lens is also important, as most modern camera lenses contain UV blocking materials and as such are not ideal for UVA imaging. The Asahi Ultra Achromatic Takumar 85 mm f4.5 lens contains quartz and calcium fluoride lens elements rather than glass and as such is ideal for imaging in UV, visible and IR. Other lenses which are constructed using elements ideally suitable for UV reflectance photography include the UV-Nikkor Macro 105 mm f4.5 (currently manufactured as the Rayfact PF10545MF-UV), the Hasselblad 105 mm f4.3 UV-Sonnar and the Jenoptik 105 mm and 60 mm macro lenses. Some normal camera lenses can be used for UVA photography; however the lens elements will absorb considerable amounts of the UVA compared to the more specialized lenses mentioned above, and any light transmitted will be towards the long wavelength end of the UVA spectrum. Any normal camera lens which is intended to be used for UV reflectance imaging should ideally be tested against one of the more specialized UV lenses for suitability.

As with lens choice, the correct filter to enable UV to pass while preventing transmission of visible and IR is vital to enabling UV reflectance photography. A wide range of filters exist which claim to be suitable for UV photography; however careful choice needs to be made for UV imaging using modern digital cameras. This issue comes about due to the sensitivity of camera sensors compared with film. The earlier types of UV passing filters, such as B + W 403, Kodak #18A, Schott UG1, Schott UG11 and Hoya U-330 to U-360, do let UVA and even in some cases UVB pass through and block the majority of the visible light. However they also let through varying degrees of IR light. In the days of using film, this wasn't a problem—orthochromatic film which was sensitive to UV light was not IR sensitive. As a result it didn't matter whether the filter let IR through or not. Modern camera sensors are highly sensitive to IR, much more so than they are to UV. Therefore filters which pass even small amounts of IR are to be avoided, or IR blocking filters are to be used in combination with them. Many researchers involved in UV reflectance imaging use the current version Baader Planetarium Ultraviolet Venus filter (commonly known as the 'Baader U') as this is extremely effective at blocking IR. Other potential filters for UVA reflectance imaging include the LaLa U (offered by UVIROptics, USA) and the conversions offered by Advanced Camera Services Ltd, UK, as these are also highly effective at blocking IR.

If polarized UV imaging of the skin is to be done, the light source and the camera lens will need polarizing filters. This presents further complications for the UV skin researcher, as most conventional polarizers are highly UV absorbing. One way to deal with this is to use dedicated UV polarizing filters which are however extremely expensive. Some early linear polarizers let enough UV light through to be useful for UV reflectance photographer in the UVA region. The researcher should ideally check suitability with a UV-Vis spectrometer before use as not all linear polarizers let through sufficient UV light to be useful.

Choice of light source is also important. Sunlight is composed of a wide range of wavelengths from UV through to IR; however its intensity (and distribution of wavelengths) varies as a function of time of day, time of year, geographical location and cloud cover, so it is far from ideal for use as a research light source. Camera flashes normally have coatings or filters on them to minimize the amount of UV they emit. These can be modified, by removal of the filters and/or coatings, to emit more UV and are a useful light source for the UV researcher. Also the choice of bulb, for flashes which can have the bulb changed, can be optimized for UV emission too. Standard studio flash units are often supplied with glass flash tubes which are coated to correct the colour temperature to 5500 K. These tubes can be used for UV imaging; however they are not ideal, as the coating drastically cuts down the UV emitted. Uncoated glass flash tubes are a better choice than the coated ones—in experiments carried out by the author, using Bowens GM500 flash units, moving from coated to uncoated glass flash tubes resulted in about a 1.5 stop improvement in light for UV imaging using a converted camera and Baader U filter. The uncoated tubes are often available as replacement items either from the original flash manufacturer or a third party. Some studio flashes also have quartz tubes rather than glass ones. Quartz can let through UV down to below 200 nm, however not all quartz used in flash tube has high UV transparency, and the user should if possible check for suitability using a spectrometer before assuming that they emit more UV than uncoated glass tubes. One thing which must be considered when using these for in vivo imaging is the exposure of the subject to UV light. Therefore both the wavelength distribution and intensity of the light sources must be assessed before being used to illuminate the skin [30]. Putting all of these factors together—camera choice and modification, lens, filter and light source—can enable the skin researcher to capture cross-polarized UV images of the skin and sunscreen films in vivo, such as shown in Fig. 29.4 [31].

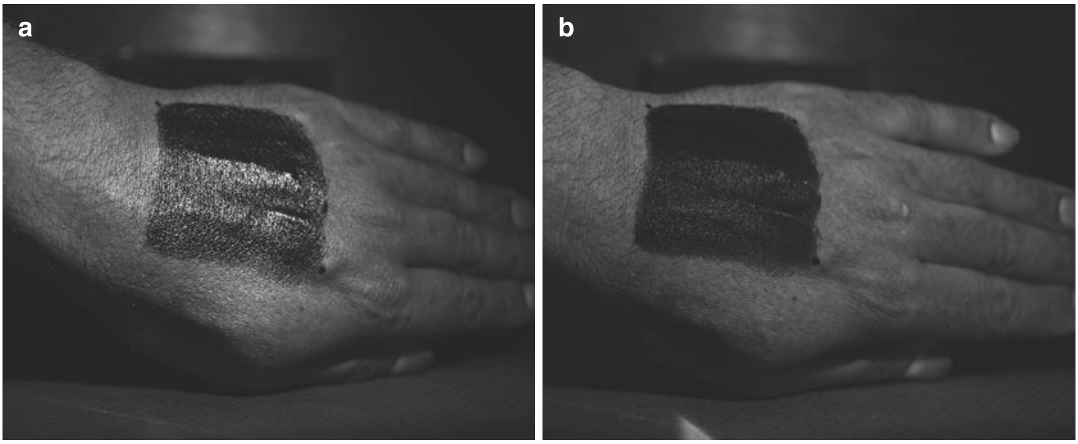

Fig. 29.4 (**a**) Normal and (**b**) cross-polarized UVA image of an SPF50 sunscreen film applied to the skin at a dose of 2 μl/cm^2

Figure 29.4a, b was captured using a monochrome-converted SLR camera (Bayer filter and internal UV/IR blocking filters had been removed), a standard camera lens, a commercial camera flash which had been modified to make it into a UV flash, a Baader U filter and a pair of linear polarizers (one on the flash, the other on the lens, set at 90° to each other). As can be seen, the sunscreen film on the skin appears dark as it is strongly UV absorbing, even in the UVA being imaged here. The non-polarized image shows the shine bands on the sunscreen typically seen when photographing topical creams using flashlight. Cross-polarizing the light source and camera effectively eliminates this shine and enables the amount of UVA being absorbed by the film to be imaged. By eliminating the shine bands from the product which normally hide the amount of UV being absorbed, cross-polarized UVA imaging is directly applicable to areas such as measurement of sunscreen wash-off in vivo in real-life usage situations.

As with visible light imaging, calibration of the amount of UVA being reflected from the skin surface can be extremely useful, for example, when trying to understand the amount of UV being absorbed by a sunscreen film. Standard camera calibration charts are unsuitable for UV reflectance photography, as their optical properties vary substantially across the UVA range. However it is possible to use Spectralon® standards or for the skin researcher to make their own standards using a mixture of carbon black, plaster of Paris and magnesium oxide, to establish the amount of UVA being reflected from the skin during imaging [32].

29.3 Infrared (IR) Imaging of the Skin

As well as the forensics aspects of skin imaging mentioned elsewhere in the chapter, there has been a recent rise in interest in the potential of topical products to provide IR protection to the skin, in addition to reducing UV exposure [33, 34]. Consideration of protection against excessive exposure to IR radiation makes sense; while it doesn't have the direct DNA damaging effects of the shorter wavelength UV, it comprises a much higher proportion of sunlight (6.8% UV, 38.9% visible, 54.3% IR) [33]. IR light exposure has been linked to oxidative stress in the skin, and also to adverse effects associated with excessive heat. IR-A radiation (700–1400 nm) has been linked with regulation of a wide range of genes in the skin, including roles in regulating extracellular matrix (ECM) homeostasis, cell growth and apoptosis and stress responses. IR-B (1400–3000 nm) and IR-C (3000–1 mm) radiation is more responsible for increasing skin temperature during exposure to the sun and is implicated in destruction of collagen and elastin, as a result of this temperature increase. This is characterized by an increase in the expression of matrix metalloproteinases (MMPs) [35].

However the role of IR radiation in skin damage is far from simple, and while there are negative aspects to excessive heat, IR exposure has also been linked with improvements in skin healing [33] and even to be important in reducing the effects of UV-related skin damage by reducing DNA damage and the upregulation of antiapoptotic proteins [36]. It is likely therefore that like with UV exposure where low levels of UV are required for the production of vitamin D, while higher levels result in sunburn and increased risk for the formation of melanoma, a certain level of IR exposure is required for the proper functioning of the skin, while excessive levels should be avoided.

Imaging of the effects of IR on the skin and topical IR protection can be done in a variety of ways. The change in skin visible redness as a result of heat can be done using visible light photography, concentrating on red channel in the images [37, 38]. The red channel gives the researcher information on the degree of erythema within the skin, with the link being that increased temperature of the skin increases the blood flow and also that increased thermal exposure can result in irritation. This is the principle behind the erythema measurement with the TiVi700 Tissue Viability Imager from WheelsBridge AB, Lövsbergsvägen, Sweden [39]. Also thermal imaging can be used to directly measure temperature changes [38]. This technique focusses more on imaging the longer wavelength of IR from 1000 nm up to 14,000 nm, associated with the temperature of the skin. Like photographic imaging, thermal imaging can be useful for the skin research as it is noncontact method of visualising the skin, although when measuring the temperature of the skin, it is vital to tightly control the temperature of the test facility to minimize the effect of the environment on the measurement [40].

Noncontact thermography has also been used to assess changes in skin temperature as a function of physical exercise where it can be used to provide insight into the efficiency and effectiveness of physical training for athletes [41], as well as in the diagnosis of skin conditions such as allergies, blister formation and burn/wound healing [42].

Optical coherence tomography (OCT) relies on the ability of IR to penetrate relatively deeply into the skin to provide structural information. A technique which was originally applied to ophthalmic research it has recently been more widely used in dermatology [43, 44]. It enables high-resolution imaging of microstructures and the layers within the skin and has demonstrated the ability to identify layers and structures of the skin such as the epidermis, dermis, sweat glands, hair follicles and blood vessels, as well as tumorous lesions [45, 46]. The axial resolution of OCT is directly related to the spectral bandwidth of the light source. However, the lateral resolution is linked to the depth of focus and remains limited in standard OCT. The studies on the skin published so far showed a resolution of the order of 5–10 μm. While the technique can be used to look at the skin in general, the resolution of 5–10 μm does limit its use for measurements within the SC over most of the body, although it has been reported for corroborating the ability of in vivo confocal Raman spectroscopy to measure SC thickness based on the shape of water distribution profiles [47]. By combining OCT with high numerical apertures, the resolution can be improved and allows for cellular-level transverse imaging. Gabor-domain optical coherence microscopy (GD-OCM) makes it possible to achieve 2-μm axial and transverse resolutions for in vivo applications. A recent paper demonstrated cellular OCT images of 3D features enabling to differentiate a cancerous skin from a normal skin [48]. Another approach is full-frame OCT (FF-OCT) which records 2D images derived from a combination of interferometric images [49]. This high resolution now enables the technique to be used to provide optical biopsies of the skin with a similar resolution to conventional histology. An example, comparing a full-frame OCT (FF-OCT) image with histology of the skin, is given in Fig. 29.5.

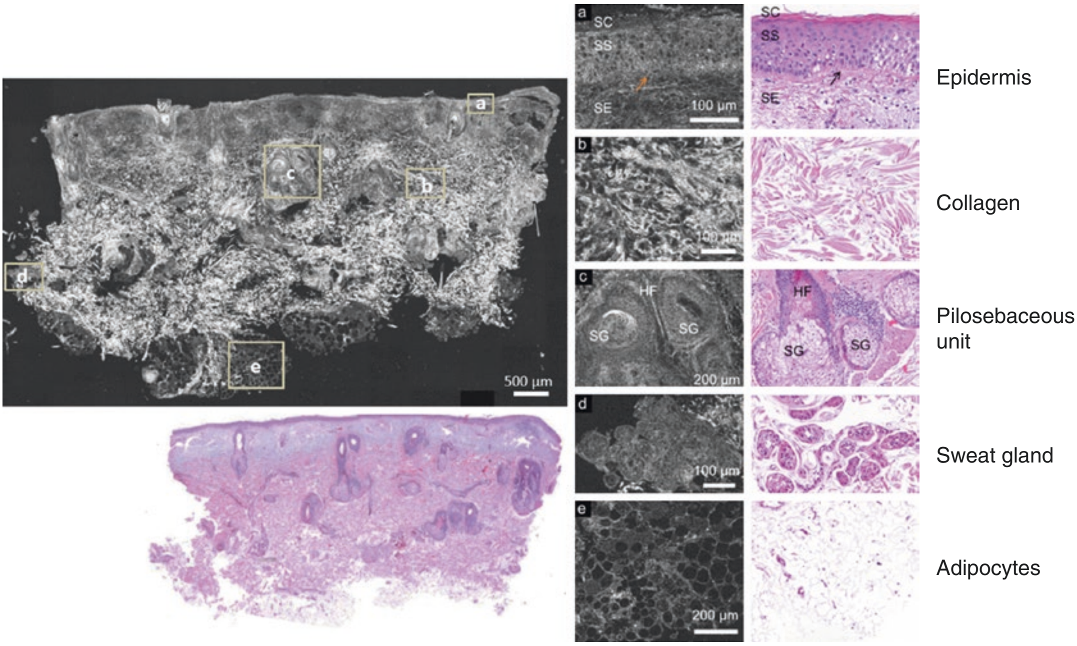

Fig. 29.5 Comparison between FF-OCT (black and white images) and classical histology of the skin (Reproduced with permission from Ref. [50])

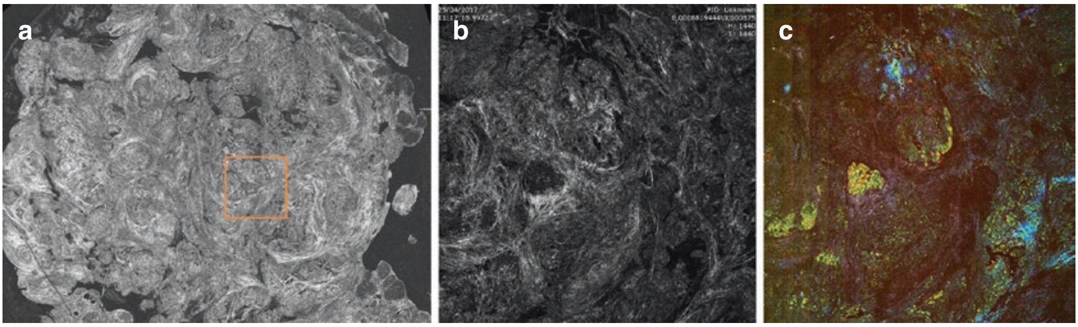

Fig. 29.6 Comparison between FF-OCT and DCI image of basal cell carcinoma containing the skin: (**a**) full size FF-OCT image of 8.5 × 6.5 mm^2, (**b**) FF-OCT image of orange square region (1.3 × 1.3 mm^2) and (**c**) DCI image of the orange square region of the full-size FF-OCT image (1.3 × 1.3 mm^2) (Reproduced with permission from Ref. [50])

Figure 29.5 demonstrates how the features in the skin identified using classical histology can also be seen in the FF-OCT image, enabling faster examination of the skin structure by eliminating the need for complex fixing and staining of the sample. Commercially available high-resolution FF-OCT systems are manufactured by LLTech, Paris, France, and imaging with the device can be carried out either in vitro or in vivo.

A very recent evolution of the FF-OCT system has now allowed differentiation of cells based on their cellular metabolic activity as part of the image capture process. Known as dynamic cellular imaging (DCI), this aids in the identification of cells during optical biopsy collection, as it provides a direct measure of intracellular activity and movement [50]. An example DCI image of a basal cell carcinoma is given in Fig. 29.6. As can be seen from Fig. 29.6, DCI enhances the ability of identifying different cell types from the image and highlights cancer cell nests. Currently the DCI technique must be carried out on skin biopsies, soon after removal of the skin for the cells to still be viable; as such it is an in vitro rather than an in vivo technique.

29.4 Fluorescence Imaging of the Skin

As mentioned above, when UV light interacts with the skin, it can be absorbed, reflected without changing wavelength, or it can absorb and then longer wavelength light re-emitted by the process of fluorescence. Imaging this light is simpler for the researcher from the point of view of the camera equipment required—as it is typically visible light that is re-emitted, standard lenses and cameras can be used. In the case of UV-induced IR fluorescence, where IR light is produced, then the same recommendations for IR photography must be followed. The complexity with implementing this technique comes from blocking all other potential light sources from the skin and camera during the photographic process. In the case of skin imaging, the area being imaged must be kept in darkness, which is relatively straightforward for smaller body sites; however if larger areas are to be imaged, they can become complex.

29.4.1 Dry Skin Fluorescence Imaging

When UVA light shines onto the skin, it can interact with the skin in a number of ways [51]. It can be reflected from the skin surface with the same wavelength, or it can be transmitted deeper into the epidermis where it can be attenuated by the melanin. UVA which has passed into the epidermis and is not attenuated by the melanin can pass deeper into the dermis where it can interact with collagen. Cross-linked collagen fluoresces under UVA, resulting in the emission of visible light. Along with fluorescence from collagen, when UVA strikes the surface of the SC, if the SC is dry, these dry corneocytes can also fluoresce resulting in the emission of visible light. This principle of UV-induced visible light fluorescence (UVVLF) is the principle behind the use of the Visioscan® VC98 camera (Courage and Khazaka electronic GmbH, Germany) for dry skin imaging [52].

The Visioscan® camera uses a light source rich in UVA to provide greyscale images 6 × 8 mm in size and can be used in vitro as well as in vivo. Uses for the device have included imaging of psoriasis [53], sunscreen remanence on the skin [54], imaging of mosaic melanoderm patterns [55], as well as dry skin assessment [56]. As well as images showing the appearance of the skin, image analysis can be carried out to determine the amount of dry skin present, as dry skin fluoresces strongly and appears white. Example in vivo images from normal, dry and very dry skin are shown in Fig. 29.7. The Visioscan® images in Fig. 29.7 clearly show the dermatoglyphic pattern on the skin; however it can also provide information as to the distribution and location of dryness on the skin. In normal skin as shown in Fig. 29.7a, the edges of the dermatoglyphic lines do not show any sign of the whitening which would be indicative of dry skin. As the skin starts to dry, as shown in Fig. 29.7b, the dryness initially becomes apparent along the edges of the dermatoglyphic lines; however the plateau regions between the dermatoglyphics do not show signs of fluorescence. In cases of extreme dryness, such as in Fig. 29.7c, fluorescence is now seen not only at the edges of the dermatoglyphic lines but also across the plateau regions between the lines, indicating a more widespread drying of the skin. The ability to visually observe the location drier parts of the skin provides an insight how the dryness evolves and progresses. The dermatoglyphic lines move like an accordion as the skin is flexed, so the regions around their edges are subject to bending and flexing forces. In normal skin which does not show signs of excessive dryness, the SC maintains its flexibility and is able to move as we do. However as the SC starts to dry out, it loses its flexibility and becomes stiffer. It is on these areas along the edges of the dermatoglyphic lines which are subject to high bending forces that the drier and stiffer SC can no longer flex as easily, and it begins to delaminate. Once that process begins, the corneocyte layers start to become detached from the skin

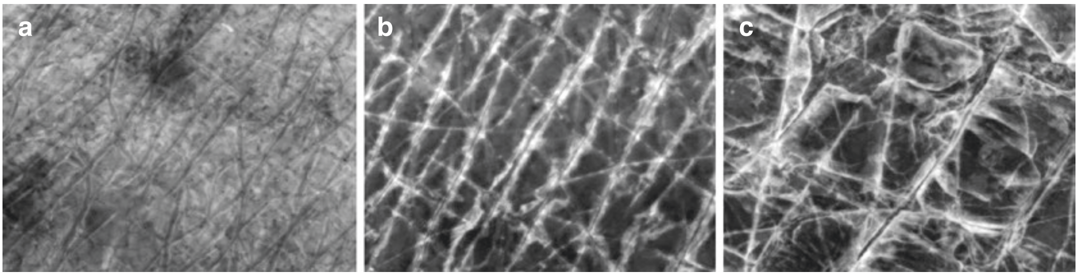

Fig. 29.7 Visioscan® images from (**a**) normal, (**b**) dry and (**c**) very dry skin

and become exposed to the air on both the top and bottom sides, further accelerating their drying rate. In cases of extreme dryness, even the SC between the dermatoglyphic lines starts to dry out and crack, as can be seen by the widening extent of the fluorescence in the Visioscan® images. In this way fluorescence imaging of the skin can provide a valuable insight into the aetiology of dry skin and emphasize the need to maintain SC flexibility, especially at the edges of the dermatoglyphic lines, and areas of the skin which are subject to a high degree of bending and flexing. Recently, capacitance imaging devices have been developed and made commercially available for research, which can be used to show how the hydration of the skin varies between areas of the dermatoglyphic lines and regions in between [57–59]. Also the EEMCO skin hydration measurement guidelines have been updated to incorporate these new techniques [60]. This demonstrates the need to consider the heterogeneity of the skin when considering whether it is dry or hydrated and when developing products to address that dryness. It is not simply enough to consider that the skin is homogeneously ‘normal’ or ‘dry’, and maintaining the flexibility of the SC, especially in areas subject to a high degree of flexing and bending such as the edges of the dermatoglyphic lines, can be crucial to preventing further drying and cracking.

29.4.2 Fluorescence Imaging of the Skin Microbiome

Illuminating the skin with UVA produces a strong fluorescence effect in the visible light part of the spectrum. Part of this fluorescence comes from porphyrins from bacteria present on the skin surface. This effect can be used to derive information on the presence and location of certain bacterial species on the skin, based on the colour of the fluorescence. This colour is driven by the chemical characteristics and structure of the porphyrin and as these are specific to certain bacteria can be used to identify bacterial species present [61–63]. An example of UV-induced visible light fluorescence image of the skin is shown in Fig. 29.2a, along with a close-up of the cheek region in Fig. 29.2b.

As can be seen in Fig. 29.2, there are bright points of light on the skin’s surface which exhibit a variety of colours. These points of lights are associated with the pores on the skins surface, and the colour of the light produced is driven by the fluorescence of the porphyrins present. The lipophile *Propionibacterium acnes* (*P. acnes*) fluoresces strongly in the orange-green part of the visible spectrum, specifically in the 570–630 nm region. This is due to the porphyrin Coproporphyrin III (CpIII). The difference in wavelength produced allows porphyrins to be differentiated from each other; for example, protoporphyrin IX (PpIX) mainly fluoresces in the red part of the spectrum >630 nm [62]. By imaging the fluorescence of the skin and looking at the different colour channels, it is then possible to identify the locations with higher levels of *P. acnes* bacteria, by looking for the green channel fluorescence (Fig. 29.8).

By splitting the visible light signal into the red and green channel measurement of CpIII and PpIX fluorescence signals in full-facial images of acne subjects, an association of the lesion-specific inflammation (acne spots) with the papulopustular lesions has been demonstrated [62, 63].

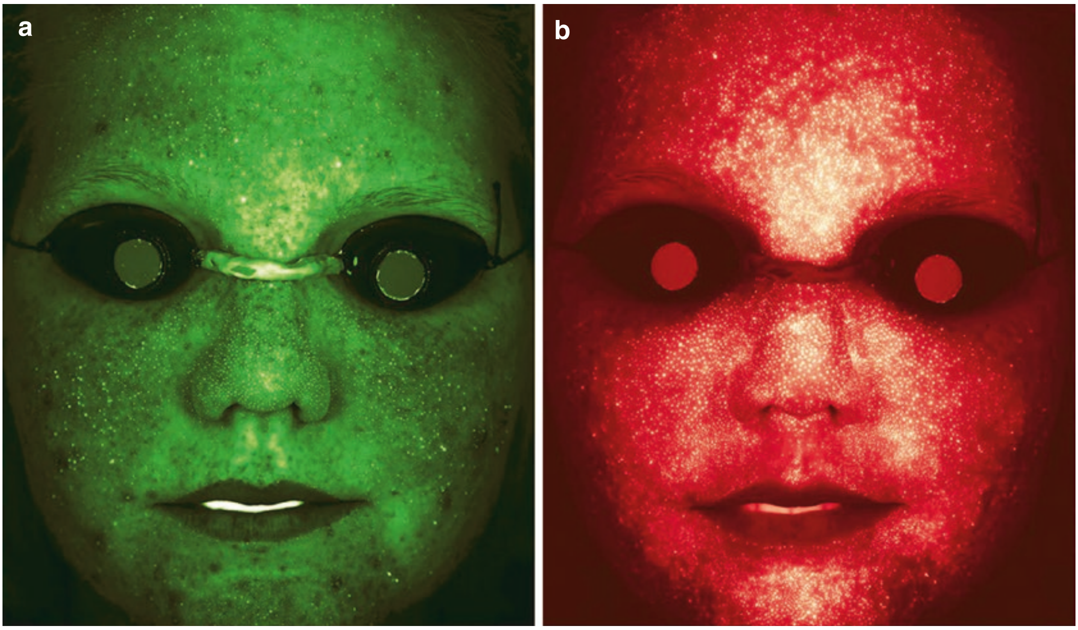

Fig. 29.8 Facial porphyrin distribution of (**a**) CpIII fluorescence and (**b**) PpIX fluorescence of a subject shows that the PpIX fluorescence spots are mainly localized in the T-zone and area surrounding the nose, while the CpIII fluorescence spots can be located anywhere on the subject's face (Reproduced with permission from Ref. [62])

The ability to derive information on the nature of the bacteria present on the skin, based on the colour at which their porphyrins fluoresce at, opens up possibility of mapping bacteria distribution on the skin, for instance, during the progression of atopic eczema [64], or even the process of washing and cleansing of the skin [65], where the normal bacterial population of the skin can become disturbed.

Commercially available imaging systems which use this phenomenon to image porphyrins on the skin include the Visia (Canfield Scientific, Inc., USA) and Visiopor PP 34 N (Courage and Khazaka electronic GmbH, Germany).

29.4.3 Fluorescence Imaging of Diseased State Skin

Under specific light illumination, particularly UV and near-UV light stimulation, the skin produces both specular light reflectance and, possibly, specific fluorescent emission. These properties offer diagnostic clues and disclose some peculiar functions of the skin. A series of superficial infections (erythrasma, some tinea capitis types, tinea/pityriasis versicolour, dermatophytoses, etc.) and of pilosebaceous follicles enriched with *Propionibacterium* spp. show fluorescence [66]. This characteristic is however reduced or lost while on some anti-acne treatments [66]. A quenching effect of fluorescence is observed following the application of sunscreens, presumably as a result of the amount of UV being absorbed by the sunscreen itself before it reaches the skin.

It must be kept in mind though that minor changes in the cause of a disease state can have a huge impact on the behaviour of the skin under UV light, for instance, the case of the common scalp infection, tinea capitis. The infection often appears as mild scaling and little hair loss, a result of the prominence of *Trichophyton tonsurans* (the most frequent cause of tinea capitis in the United States) [67]. When imaged under a UV-emitting Wood's lamp, *T. tonsurans* does not fluoresce, unlike the common tinea capitis causing organism in Europe and many other countries which exhibit a green fluorescence [67]. As a result *T. tonsurans* tinea capitis is frequently misdiagnosed because the lesions mimic such common scalp conditions as dandruff and seborrhea. Trichoscopy in combination with UV light, at a wavelength covering the spectrum of Wood's lamp, has been reported [68]. This feature can be used to increase the diagnostic potential of trichoscopy in certain forms of tinea capitis, pityrosporum folliculitis and various types of porphyria.

The colour of the fluorescence can also aid with identification of the skin condition. For instance, erythrasma has been shown to fluoresce with a strong red colour under illumination by Wood's lamp [69, 70], whereas pityriasis versicolour fluoresces with a strong yellow gold appearance under the same lighting [71].

It isn't only visible light that is emitted by fluorescence under UV light. UV-induced UV light fluorescence photography, where one wavelength of UV is used to initiate fluorescence at a different UV wavelength, has been used to image rapidly proliferating epidermal skin lesions by capturing endogenous fluorescence emissions attributed to tryptophan [72]. Specifically, a variety of skin lesions demonstrated increased endogenous fluorescence at 340 nm wavelength upon excitation and at 295 nm in rapid epidermal proliferations. These included psoriasis, actinic keratoses and basal cell carcinoma, compared with the surrounding normal skin. Conversely, non-proliferating lesions showed decreased fluorescence. However, it must be kept in mind that whenever UV light is being used to illuminate the skin, it is of paramount importance to consider the exposure of the subject to UV and also to ensure the clinician performing the imaging, and the subject is wearing appropriate UV eye protection [30]. This safety aspect is particularly important in this example as the illumination source is UVB (295 nm), as opposed to the more commonly used UVA sources, as UVA sources often emit some visible light at the blue end of the spectrum and can therefore be seen by eye.

29.4.4 Fluorescence Lifetime Imaging (FLIM)

In addition to assessing the wavelength of light being emitted as a result of the fluorescence process, the lifetime of the fluorescence process can provide insight into the processes and structure of the skin [73, 74]. Fluorescence lifetime imaging (FLIM) measures the arrival times of the emitted photons with regard to the femtosecond excitation pulses. For example, FLIM can be used to differentiate between NAD(P)H and flavoproteins as fluorophores in the upper epidermis and the lower epidermis (basal cell layer) with melanin as the major fluorophore from healthy skin [73]. Also FLIM has been used to measure the effects of cortisone treatment to patients suffering from severe dermatitis [75]. The clinicians found a strong correlation between the strength of disease and the mean autofluorescence lifetime of the epidermis and observed a lifetime decrease as a result of treatment (Fig. 29.9).

In FLIM assessment of dermatitis, the normal, no-disease-state skin, had the shortest fluorescence lifetime and that the time increased as the degree of inflammation worsened. Tuning the excitation wavelength provides information on the multiphoton excitation spectra per pixel, for example, splitting intra-tissue tattoo pigments in different spectral channels, based on the lifetime of their fluorescence signal [73].

The principle of using FLIM with confocal laser scanning microscopy of in vitro models and mice has been around for more than 20 years [76, 77]. However, the use of FLIM techniques in clinics has been limited to some research activities in the field of ophthalmology [73] and brain surgery [78]. With the availability of multiphoton tomographic systems, in vivo human clinical FLIM of autofluorescence in skin became reality. FLIM systems are currently marketed by JenLab GmbH, Germany. There is a trade-off with these types of high-resolution imaging systems, in that they can only assess a small area of the skin. However, by using a motorized in vivo adaptor, a larger skin area of up to 5 × 5 mm^2 can be measured, although obviously this does have an impact on the time required to be taken to collect the data.

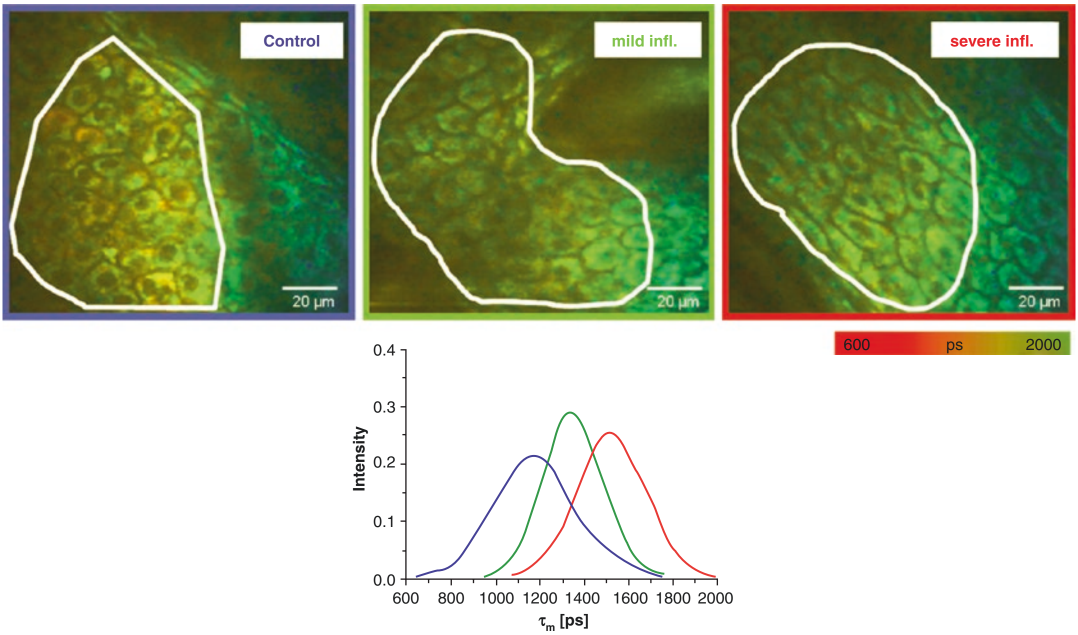

Fig. 29.9 FLIM images from clinical assessment of patients suffering from dermatitis demonstrate a clear correlation between autofluorescence lifetime and the extent of the disease. Healthy skin (blue) has a shorter mean fluorescence lifetime than skin areas with 'mild' dermatitis (green) and severe disease (red). Successful treatment results in shortening of the mean fluorescence lifetime (Reproduced from Ref. [73] with permission from Taylor & Francis Ltd (www.tandfonline.com))

29.5 Forensic Examination of the Skin

The field of forensic examination has a long history of using UV, IR and fluorescence imaging of the skin to emphasize the presence of damage [7–9, 79].

As UV reflectance imaging produces images which are highly localized to features towards the surface of the skin, it has been used to visualize old trauma injuries, for instance, burns, bites and damage caused by implements [79]. The UV enables slight differences in skin tone, which may not be visible under visible light to be captured. The reasons for the differences in skin tone changes after the injury are not fully understood, although it is believed that the loss of melanocytes from the area of injury could result in a lightening of the skin under UV reflection.

IR imaging is used to look for damage deeper within the skin, as it penetrates the epidermis and can be used to photograph features within the dermis, such as the vasculature. The degree of oxygenation of the blood has an effect on the amount of IR being reflected—venous blood strongly absorbs IR, while oxygenated blood reflects IR [80]. This can enable the technique to show up features such as varicose veins.

UV-induced visible light fluorescence can also be used to emphasize the position and locations of skin damage such as burns [81]. The advantage here over reflected UV imaging is the special camera conversions which are not required—a standard camera can be used in conjunction with a UVA light source. The reason this shows up the damage is likely to be similar to the effect in UV reflectance imaging, in that the newly re-grown skin has fewer melanocytes. With fewer melanocytes there is less absorption of the UVA from the light source, and therefore the relative proportion of UV-induced fluorescence to UV absorption will increase in the damaged area, making the skin in that location appear lighter under fluorescence.

Table 29.1 Summary of the imaging methods described in the chapter, along with key usage areas

Imaging method	Key usage areas
Ultraviolet (UV) reflectance imaging	Melanin imaging Sunscreen application imaging Surface topography imaging Forensic imaging
Cross-polarized UV reflectance imaging	Melanin imaging Sunscreen homogeneity
Infrared (IR) imaging	Erythema imaging Thermal imaging Forensic imaging
Optical coherence tomography	Skin thickness Skin refractive index measurement Skin structure visualization
Fluorescence imaging	Dry skin mapping Skin surface bacterial imaging
Fluorescence lifetime imaging (FLIM)	Assessment of physical structure and biochemical processes occurring within the skin

29.6 Conclusions

UV, IR and fluorescence imaging of the skin, while at times adding some complexities to the logistics of image capture, can provide novel insights into skin form and function which are impossible to observe with standard visible light photography. Through the correct choice of camera system, lens, lighting and filter, a wide range of skin conditions can be imaged by the researcher. However it is vital to consider all aspects of the imaging process, especially when dealing with non-visible light imaging, to ensure the reliable and reproducible images can be captured.

A summary of the imaging methods described in the chapter can be seen in Table 29.1.

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Medical Thermography

30

Luis Monje-Arenas and Néstor Pérez-Mallada

Contents

30.1 Definition

Thermography is a technique that allows visualizing and accurately measuring the temperature of bodies, without the need of physical contact since it captures infrared radiation they emit. Medically, it allows registering the cold and hot areas of a patient's body thanks to the energy radiated by their skin, with a precision that can reach up to one hundredth of a degree centigrade [1] (Fig. 30.1).

30.2 Spectral Regions

As is well known, the human eye can detect a small portion of the electromagnetic spectrum, whose wavelength is between violet 400 nm and deepest red 700 nm (0.4–0.7 μm). Beyond this dark red, there is a vast spectral region called infrared that ends at 1000 nm the point where the microwave region begins [1].

From a practical point of view, the infrared region can be subdivided into two large regions: (a) the *near infrared* or *NIR* region (0.7–1.4 μm), capable of being captured by any CCD or CMOS photographic sensor prepared for infrared, and

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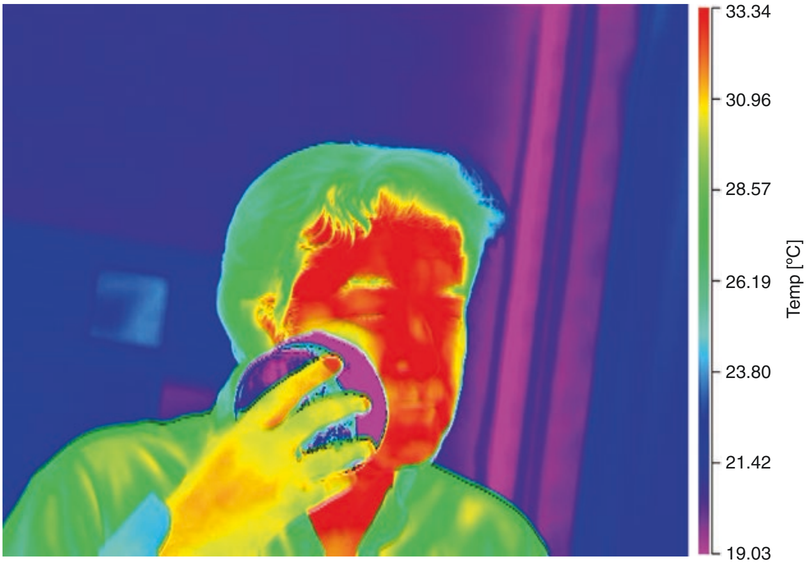

Fig. 30.1 Thermographic image of the face of one of the authors after rubbing his cheek with a can of frozen film

Table 30.1 Infrared spectrum regions

Name		Abbreviation	*λ*, µm	Band frequency, THz	Characteristics
Near infrared		NIR, IR-A	0.7–1.4	400–214	Photographic region (CCD and CMOS)
IR thermographic region	Short-wavelength infrared	SWIR IR-B	1.4–3	214–100	Cooled cameras
	Mid-wavelength infrared	MWIR IR-C	3–6	100–37	Cooled cameras
			6–8		Not useful Opaque atmosphere
	Long-wavelength infrared	LWIR IR-C	8–15	37–20	Non-cooled microbolometers (8–12 µm also cooled)
	Far infrared	FIR	15–1000	20–0.3	Interferences with atmosphere

(b) the *far infrared* or *IR thermographic region* (1.4–1000 µm), which is susceptible to partial registry through the use of thermal imaging cameras with special sensors. This chapter will mostly deal with this region as it is the one with the greatest medical applications.

The thermographic region is subdivided into two subsets: (a) *medium infrared*, which is the one that interests us and comprises the *short wave* region or SWIR (1.4–3 µm), *medium* or *MWIR* (3–8 µm), and *long* or *LWIR* (8–15 µm), and (b) the *far infrared FIR* (15–1000 µm) has scarce practical use [2] (Table 30.1).

Cameras capture the body's *reflected radiation* which belongs to the closer infrared regions (NIR and SWIR); the middle regions (MWIR and LWIR) are captured by *radiation* emitted from the body, since any object above of zero degrees Kelvin (−273.15 °C) is capable of emitting infrared radiation.

Atmosphere, water vapor, carbon monoxide, nitrogen, ozone, and even the heat emitted by the Earth itself create a series of barriers and interferences that allow only certain regions to be of thermographic utility for medical applications. These regions are called *infra-*

red windows, and they mostly belong to the MWIR and LWIR bands.

30.3 Thermographic Camera

A thermal camera consists of the following components:

- *Lenses*: the lenses for thermography are manufactured with materials permeable to the entire infrared spectral band and have a characteristic opacity. The most common materials are germanium, silicon, and zinc selenide (Fig. 30.2).
- *Detectors*: are matrixes of sensors placed in the focal plane of the lens. The distance between the center of two adjacent sensors is called pixel pitch (also referred to as "dot pitch") and is measured in millimeters (written in the form of p(mm)). Together with the number of sensors pixel's pitch is what determines the resolution of the detector, which usually has between 60,000 and 1,000,000 sensors.

Depending on whether the detectors have an inner cooling system or not, there are two types of cameras and detectors [3, 4] (Fig. 30.3).

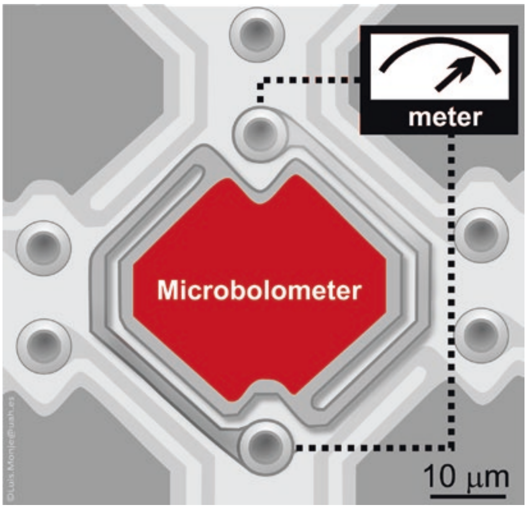

Fig. 30.3 Top view of a plate of romboidal microbolometers. Note the long isolation pins (Original image by Luis Monje)

- *Uncooled microbolometers*: consist of a matrix of microbolometers that, in essence, are plates of vanadium oxide or amorphous silicon attached to the base by two small legs that work as insulators. The infrared image (in the spectral band between 8 and 13 µm) once projected on each microbolometer heats proportionally the plate modifying their electrical resistance, which translates into a greater or lesser signal intensity in each pixel. These cameras are affordable, their startup is instantaneous, their energy consumption is lower (they do not have refrigeration), and they are more robust (Figs. 30.4 and 30.5).
- *Cryo-cooled solid-state detectors*: They are based on the photoelectric effect similar to photographic sensors. They consist of a matrix of cells, each with two closed layers of doped semiconductors connected to each other by a measurement circuit. The valence layer has an electronic imbalance, and when infrared radiation hits it, it frees up electrons to the conduction layer. These electrons return to the valence shell by a circuit that measures the generated electrical current, delivering the signal of each pixel. Most detectors are composed of indium antimonide (InSb), indium gallium arsenide (InGaAs), platinum silicide (PtSi), mercury and cadmium telluride (MCT), vanadium

Fig. 30.2 Germanium lens for thermal imaging cameras

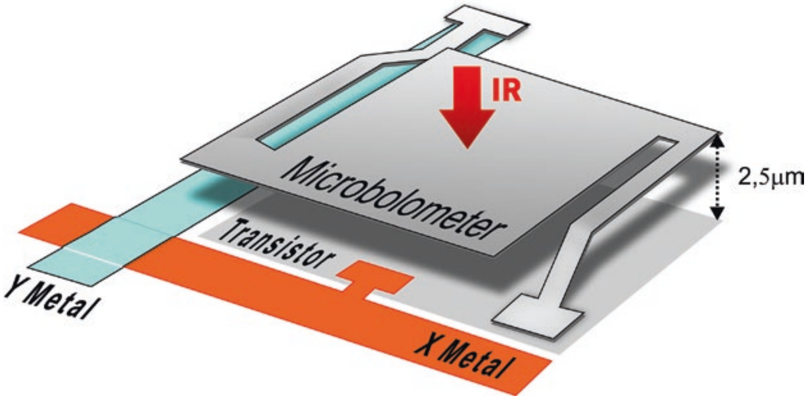

Fig. 30.4 Perspective view of a rectangular microbolometer (Original image by Luis Monje)

Fig. 30.5 High-end thermographic camera from InfraTec with microbolometer detector model VarioCAM® HD research 900, equipped with a sensor with a resolution of 1024 × 768 pixels that by an opto-mechanical scan can go up to 2048 × 1024 pixels. Its partial image speed is 240 Hz, and it has an integrated 5.6″ TFT monitor and viewfinder (Image courtesy of InfraTec GmbH (www.infratec.de))

oxide (VOx), or amorphous silicon. The material chosen determines the spectral segment to work with, since none of them is capable of capturing the entire infrared region. CO2, N^2, and O3 molecules found in water vapor in the atmosphere are opaque to infrared and act as a filter, retaining most of the infrared spectral band except in certain permeable segments called *windows*. Thanks to this, in thermography we can use IR windows of 1.4–3 µm (SWIR), 2–5.6 µm (MWIR), and 8–14 µm, corresponding to the LWIR. The detector is usually attached to a Dewar vessel (double-walled vessel containing liquid nitrogen at −200 °C) or to other types of simpler coolers based on the Peltier and Stirling effect. The reason for cooling the detector is to prevent air from the camera itself and its circuits interfering with the capture by the sensor, thus achieving greater accuracy and thermal resolution. The thermal accuracy can be ten times that of cameras with uncooled detectors and represents approximately 0.01 °C compared to the average accuracy of 0.85 °C of microbolometers (not refrigerated). Its spectral range varies between 1.5 and 5.1 μm. The cameras with cooled detector are much more expensive to manufacture and need a minimum startup time of about 7 min, although their sensitivity and resolution are much higher as their cells are much smaller and carry refrigeration. In addition, the device is larger, more delicate, and with a higher power consumption. When the subject undergoes sudden changes in temperature, the microbolometers take some time to warm up and show the effect, while in the cooled detectors, the change is almost instantaneous (1 μs), which makes them ideal for thermal analysis of subjects in movement [5] (Figs. 30.6 and 30.7).

30.4 Uses of Thermography

Due to its intrinsic characteristics, thermography is very useful for remote temperature measurements like evaluation of buildings' insulation, location of hot zones in motors and electric circuits, detection of thermal bridges, imaging people and animals in total darkness, night maritime rescue operations, gas leaks, surveillance tasks, defense and security, meteorology, and health sciences.

30.5 Medical Applications of Thermography

Thermography has been used for quite some time for the functional and clinical assessment of the human body. It has been part of a complementary evaluation system that based his diagnostic imaging potential in the detection of multiple patholo-

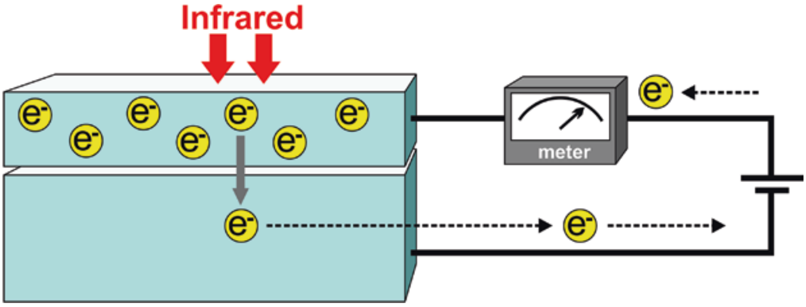

Fig. 30.6 Schematic drawing showing principle of operation for a solid-state detector

Fig. 30.7 High-end thermographic camera by Telops with solid-state detector, model HDR M100hd. It has a sensor of 1280 × 1024 pixels at 105 ips, with partial image speed of 240 Hz and a spectral range between 3 and 5 μm. Its price exceeds 190,000 USD (Image courtesy of Telops®)

gies [6]. Hyperemia (an excess of blood in the vessels supplying an organ or other part of the body) is caused by vasodilatation, and it is a sign present in multiple conditions. It causes a temperature increase, in many cases at a superficial level and from a direct or reflex effect on the vessels. It is currently being used [7] as a tool for the detection of pathologies with trophic symptomatology of thermal origin, since it is a very precise system for measuring the superficial temperature in the human body.

Recently it has been used a complementary non-invasive imaging technique to evaluate pathologies linked to breast cancer [8], such as mastitis, with the understanding that it cannot be used yet as a screening system, let alone unique, for mammary oncological pathologies [9]. For this reason, its use as an initial assessment system has been abandoned when tumor alterations are suspected, although it is still an adequate tool to control the evolution of other pathologies that may present thermal superficial alterations.

With the incorporation of new precision systems and the reduction of costs of equipment, different research works and case reviews are being carried out to incorporate thermography and evaluate its effectiveness in the management of pathologies from different medical specialties [10]. Currently, thermal image capturing has different clinical applications due to its interesting uses [11, 12] in the complementary diagnosis and evolution of the patient.

The human body has different mechanisms of thermoregulation; trophic changes are generated by physiological and physio-pathological processes that result in the loss, increase, or modification of body heat. This is linked to the vascular, neurovegetative, and musculoskeletal system. The visualization of all these changes of temperature by means of thermographic cameras is becoming increasingly accessible and can be a valuable element for detecting problems/alterations related to the physiopathology of certain injuries. Registering the succession of thermal changes over time would provide added value to the knowledge of the evolution of certain lesions, helping to select the appropriate therapy and monitoring the response to treatment. Thermal changes after the application of paraffin on the skin (Fig. 30.8), ultrasound (Fig. 30.9), infrared and hot pack (Fig. 30.10), and radial shock waves (Fig. 30.11) can be assessed by thermography [13]. In the application of therapies like short wave, microwave, or other thermotherapy equipment, there are already bioengineering investigations which incorporate thermographic technology as an adequate control system to modulate the intensity of application of these physical therapies. Having an automatic system that allows regulating the power of application by means of measuring skin and subcutaneous tissues temperature can avoid injuring tissue due to burns. This technology will surely be incorporated in future equipment in the very near future, and thermography will postulate itself as an excellent control system (Fig. 30.12).

Fig. 30.8 Thermographic application to evaluate the effect and temperature after the application of infrared thermotherapy [1]

Another use of thermography has been in the textile industry for the development of new technical fabrics. Thermal body images are used to assess body heat losses before, during, and after exercise, as well as under adverse weather conditions.

In these cases, the measurements are not related to the diagnosis and physiopathology of the body but are intended to study how the organism interacts with the environment. Detecting

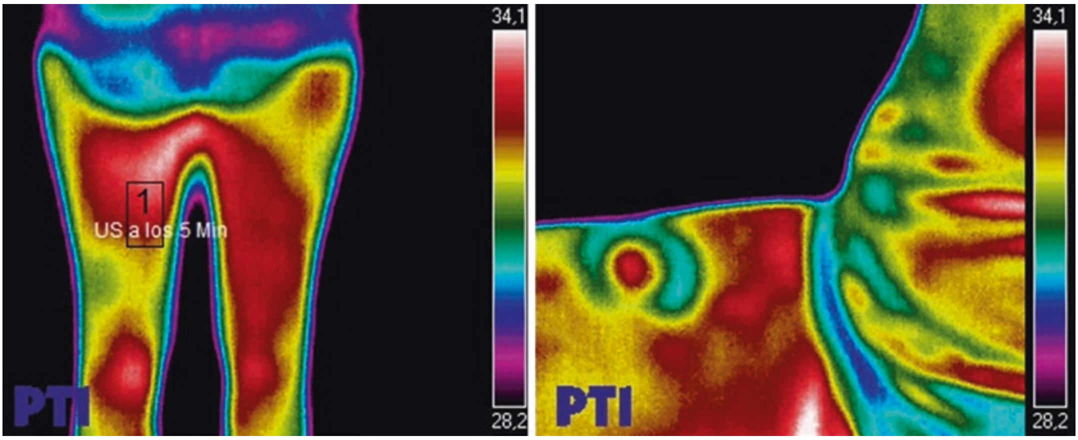

Fig. 30.9 Using thermography to measure the temperature and evaluate the effect of ultrasound

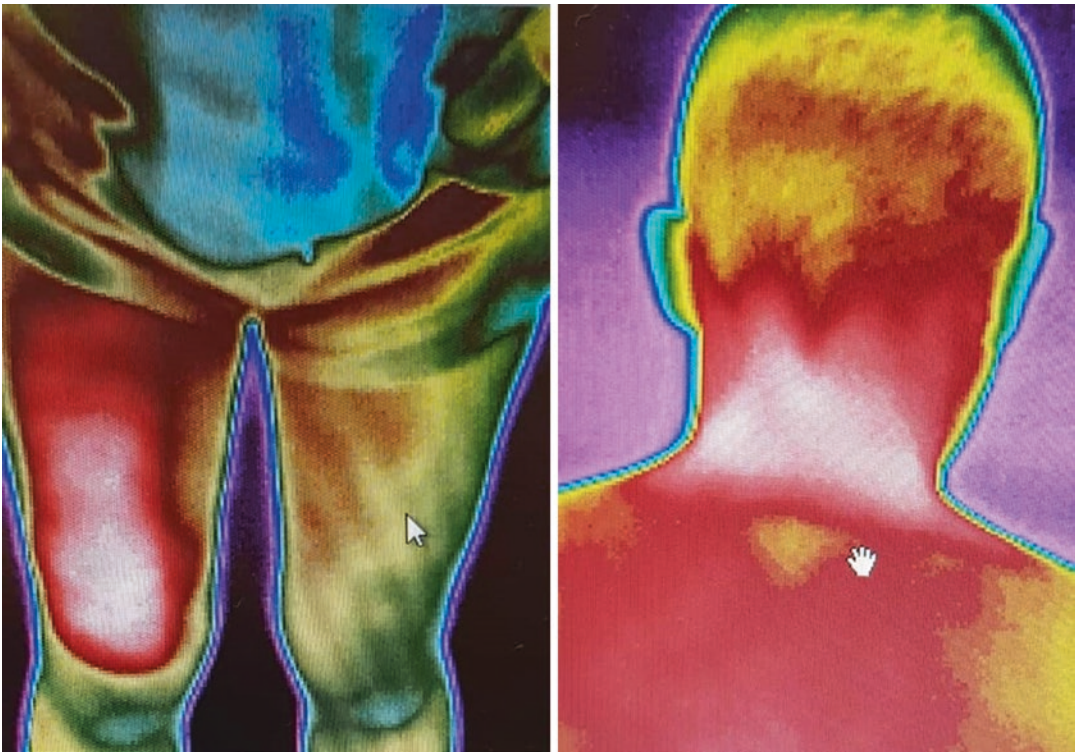

Fig. 30.10 Thermographic application to evaluate the effect and temperature after hot pack

heat leaks or checking if these could alter the mechanisms of human thermoregulation is relevant for the effectiveness and efficiency of the technical material. Multiple brands of clothing and footwear have presented studies with this tool to support the new design of materials or introduce improvements to their models.

A proper knowledge on the mechanisms involved in the physiology of the corporal thermal production and its alterations is a requirement for adequately interpreting thermal images [14]. Its complexity exceeds the purpose of this chapter. Knowing these processes is as essential as mastering the camera and its software.

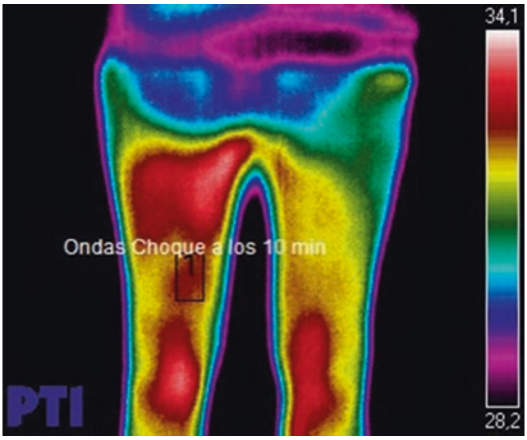

Fig. 30.11 Thermographic application to evaluate the effect and temperature after the shock waves

30.6 Current Studies of Thermography in Medicine and Health Sciences

As previously mentioned, there is a large number of medical pathologies were vascular changes are present, both as hypertrophic or ischemia. Thermal changes in the skin can be visualized and quantified by thermography. One of the clearest problems for which the diagnostic use of thermography has not become extended is probably because within the same medical specialty, (a) multiple pathologies with different symptoms do not present peripheral vascular changes, and (b) different pathologies can present similar vascular changes. This reduces the discriminatory potential of thermography to differentiate pathologies. One possible use, however, could be to monitor changes of a lesion over time or after treatment.

Fig. 30.12 Thermographic camera donated by the Clinical Research Unit in Biomechanics and Physiotherapy, San Juan de Dios School of Nursing and Physiotherapy, Comillas Pontifical University, Spain. The thermographic system www.Enraf.es, is a device equipped with a latest technology detector of vanadium oxide microbolometers with the capacity to generate thermal images of 320 × 240 pixels in the spectral range of 7.5–13.0 µm. The system makes visible differences of temperature of 50 mK and provides data of 16 bits with up to 50 frames per second with complete resolution of box of 640 × 480 thanks to its connection Gigabit Ethernet. It has a high-speed window system function that increases the frequency of output images up to 200 Hz in a window of 640 × 120 pixels

Thermography can be an excellent tool to analyze the evolution of the injury. The clearest examples are seen in the fields of physiotherapy [15], physical medicine and rehabilitation [16], traumatology [17], sport medicine [18], endocrinology [19], dermatology [20], and rheumatology, where symptomatic peripheral vascular components are present at the time of diagnosing and at follow-up.

The specialty of neurology, both in its phase of motility and in the processes of immobility, can be benefited by the use of this technique as trophic changes or vascular alterations can be present in certain conditions for certain pathologies. Thermography is a low cost, no invasive technique with no contraindications that allows obtaining information very quickly and easily. In a recent paper, Hegedus et al. [21] showed the effectiveness of using thermography as a tool for monitoring patients who had stokes (cerebrovascular accidents) by recording the trophic changes in motor or sensory areas that have suffered brain damage. The clinical incorporation of thermography would allow to know improvements obtained during the rehabilitation, such as increase in Range of Movement (ROM) that produce vascular and therefore thermal changes, as well as other mobility aspects (speed, strength, motor control) that also evolve with easily recordable trophic variations and without contraindications for patients.

The first thermographic cameras appear in the twentieth century as assessment tools in traumatic pathologies. In 1977 the use of thermal imaging as an assessment system for fractures and infections was published [22], emphasizing its importance not for the initial diagnosis or screening but as a system of assessment in the evolution of the pathology. It was also during this period that thermal therapy was used [23] to monitor patients with alterations in the locomotor system. It helped objectify clinical changes. Research with this non-invasive clinical tool in the area of fractures continues today [24] as it provides [25] an assessment and objectification of clinical changes in the injured area. In children with traumatisms, evidences have been found [26] of its usefulness as a predictive system as it can be used to rule out the existence of fractures, which suggest that it could be a promising system to incorporate in clinics.

Regarding the area of traumatology and physiotherapy [27], its use could be suitable to assess the evolution of tendinopathies of various kinds, although it is not a valid initial diagnostic system as it does not differentiate among them. However, muscular conditions like active trigger points can be diagnosed with thermography [28] as well as observe changes caused by physiotherapy. This could be an excellent tool to analyze the evolution and effectiveness of such therapies. It remains to be studied whether in latent or non-active myofascial trigger points it could be a potential diagnostic tool.

The number of articles on thermography in medicine is not high when compared to other non-invasive imaging technologies; however, there are qualitative trials on the possible professional utility that this tool can provide in clinical use with interesting results. The *Journal of Thermal Biology* published in 2017 [29] an interesting Delphi study on the interest of health professionals in this system as a potential tool for clinical assessment; further studies should be done to understand what data is important, how to standardize procedures, and how to analyze the results obtained so far. In 2018, Ginart et al. [30] compared the use of thermography with other diagnostic imaging systems in patients with cervical lesions. Again and as seen in other clinical specialties (neurology, traumatology, physiotherapy, etc.), it is a useful technique for monitoring but not to make an initial diagnosis or screening system. However, there are already investigations that are being done in the opposite direction: they have shown that thermography could be useful as an initial diagnostic tool in lumbar injuries, helping in deciding the possible physiotherapy scheme (osteopathy) [31]. On the other hand, a research work has also been published [32] (2015) using thermography to differentiate between two physiotherapy treatments for lumbar injuries. As indicated by these works, its use is highly interesting but remembering that its strength is in monitoring rather than screening and diagnosing.

Thermographic technology can also be used to analyze the resistance of orthotic material, as it can be a good system to know the stresses and fatigue of the material [33]. It could be an adequate tool to evaluate orthoses and fatigue of materials used in rehabilitation, physiotherapy, and traumatology. This field is enormous as there are currently multiple studies and research works in the development of new products, materials for orthotic systems. The use of this non-invasive technique to understand how these materials are worn out by mechanical stress could be of great help.

30.7 Final Considerations

As final considerations of the publications of recent years and as a trend in the clinical area, we could summarize that thermography:

- It's an excellent system for analyzing the evolution of lesions, especially in those pathologies that with inflammation or ischemic areas, thermal modifications easily recordable by thermographic systems.
- These systems have proven effective in recording surface temperature variations without contact with the patient. They are non-invasive systems without any contraindication for the patient as they just collect the emission of the temperature radiated by the patient's body.
- They are not an initial screening or diagnosis system capable of detecting relevant clinical aspects for their differentiation from other pathologies. The fact that thermography does not detect deep aspects can be limiting, but it can guide in monitoring and symptom assessment.
- Numerous medical specialties as well as other branches of health science have publications that provide evidence of their usefulness in evolution of conditions with trophic changes. These investigations are becoming more numerous as cost of equipment is decreasing. The use of thermography is yet not new, as it has been used since last century.
- The study of thermography in other health fields should continue in order to understand its possible clinical application and determine in which pathologies it could add value to use. There is growing evidence recently of its high interest as a non-invasive system that has no contraindications and is increasingly more accessible.

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3D Photography

31

María Luz Negrín Díaz

Contents

31.1 Introduction

Conventional clinical photography is an important tool in daily practice, since it allows us to document clinical cases and monitor treatments, providing visual support for presentations and clinical discussions: it is a powerful educational tool, and at the same time, it has medico-legal value. Three-dimensional photography represents a technological advance that contributes an important plus to clinical practice by providing a series of details in relation to the normal morphology of the human being; a 3D model is closer to reality and reduces common distortion errors found in 2D photography. It is of great aid in registering size and shape of lesions such as tumors, scars, and ulcers, and it is ideal in facial and breast registry as it facilitates comparison (before and after treatments). It is an ideal tool for plastic surgeons and cosmetic medicine since images are more realistic, and with new software it is easier to communicate possible outcomes.

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P. Pasquali (ed.), *Photography in Clinical Medicine*, https://doi.org/10.1007/978-3-030-24544-3_31

31.2 History

> *No home should be without one!*
> London Stereoscopic Company's maxim (1850s)

The phenomenon of vision has always aroused the interest of man. For centuries, many have contributed with their knowledge and research to the knowledge and understanding of a process that still continues to surprise us.

In Ancient Greece, Euclid and Ptolemy studied the phenomenon of vision and light, proposing several theorems. Five hundred years later, the celebrated physicist and Greek physician Galen dealt with the physiology of the eye and the subject of binocular vision [1]. Ibn al-Haytham, known in Europe as Alhacén (965–1039), in his work *Treaty of Optics* (Kitab al-Manazir), contributed his research on the theory of light, laws of optics, and the human visual system, some of which that are still used. Once these treatises reached Europe (around twelfth century), they contributed to the expansion of the knowledge about the theories of light [2].

Leonardo da Vinci (1452–1519) conducted studies on the anatomy and physiology of the eye, and in his treatise on painting [1, 3], he indicated that "the dissimilarity contemplated by each eye were the reason why finished paintings never produced the effect of the natural relief of objects perceived through binocular vision" [1]. Giambattista della Porta (1535–1615) used various combinations of lenses and mirrors to understand the nature of light, vision, and heat [4].

It was in the XVIII C when Isaac Newton wrote in his *Opticks: or, A Treatise of the Reflections, Refractions, Inflections and Colors of Light* (1704) that the two optical nerves "meet in the brain in such a way that the fibers create a unique image" [1].

The English physicist Charles Wheatstone (1802–1875) described in 1833 the stereoscopic vision in *Outlines of Human Physiology*, and in 1838 he presented before the Royal Society his treatise, *Contributions to the Physiology of Vision-Part the First: On Some Remarkable and Hitherto Unobserved Phenomena of Binocular Vision*, where he proposed the theory that the human brain combined the image that each eye provided separately to form a three-dimensional image [5]. He built an apparatus that would allow vision in relief from two drawings observed by a viewfinder composed of lenses and mirrors: the first stereoscope or stereoscope was born [5–7]. Wheatstone's stereoscope (1833) was considered an optical artifact with a clear scientific value [7].

The first stereoscopic camera is attributed to Sir David Brewster (1781–1868) and presented in Edinburgh in 1844. It was a binocular device that included corrective lenses "to be able to focus the images closer" and allowed taking portraits and make copy of statues [1]. A version of Brewster's stereoscope, manufactured by the French optician Louis Jules Duboscq, was exhibited at the Great Exhibition of the Crystal Palace in London in 1851, drawing the attention of Queen Victoria and provoking an authentic madness for stereoscopic photography [1, 8]. The furor that was generated was such that by 1856 more than half a million stereoscopes had been sold. This new passion crossed the Atlantic and spread in America [1].

Oliver Wendell Holmes (1809–1894) built a model of three-dimensional viewfinder that turned out to be the greatest entertainment of the bourgeoisie at the end of the nineteenth century; he referred to the stereoscopic photography saying: "The effect produced by a good photograph seen through the stereoscope generates a surprise such as no painting has produced it…" [9]. This handheld viewer soon gained popularity and was used for many years, reaching a large audience (Fig. 31.1) [1, 7].

André-Adolphe-Eugène Disdéri created a *carte de visite*, a photograph in a 6.4 × 10 cm format, which converted into stereographs of famous faces, landscapes of distant countries, and details of nature. This became the favorite pastime of the period. The success of stereography extended to America, surpassing that obtained in Europe and becoming a first visual mass phenomenon (Fig. 31.1) [1].

At the end of the nineteenth century, the enthusiasm for stereoscopy declined, because its use was limited to one person at a time and the market was filled with low-quality images and defective stereoscopes. With the appearance of the photographic film, a new type of photography was being promoted.

At the beginning of the twentieth century appeared the View Master (1935), created by William Gruber, who used Kodachrome color film. It was a success during the following years with thousands of images of monuments, landscapes, works of art, and comics (Fig. 31.2).

Fig. 31.1 Stereoscope of the late 19th century and Cartes de visite. (Photography: Author's personal collection)

From the XIX C to the recent advances in computer science, 3D images started to be used on computer monitors for different presentations in medicine, cartography, art, architecture, astronomy, industry, and many other applications [10]. These technological advances also developed in the movie industry where better 3D films have an evergrowing audience.

In the field of medicine, three-dimensional photography causes fascination as a teaching tool, in the interpretation of images for diagnosis, and in surgical interventions and representing a fundamental tool in the pre-surgical consultation, contributing in communicating procedures and projecting expected results. In 1947, the magazine *The Lancet* [11] publishes about the stereoscopic effect achieved in photography, without special equipment, only using impressed ordinary photographic material where the photographs had been taken from two different angles, at 16° difference between shots.

Another clear example is that of the renowned scientist Santiago Ramón y Cajal, passionate about photography and a great connoisseur of stereoscopic techniques, who published in his article *Stereoscopic and biplanar microphotography of nervous tissue* [12] numerous stereoscopic pairs of the neuronal system that, with all certainty, contributed in the current understanding of the neural system.

Fig. 31.2 View Master (Photography: Author's personal collection)

31.3 Stereoscopic Vision

Stereopsis is a term that describes a visual phenomenon by which we can perceive in depth the different elements of a scene, thanks to the difference that exists between the images perceived by each eye [5, 13, 14].

Each eye looks at an object from a slightly different angle, generating an image that is therefore somewhat different. It is the union or fusion of these two images originated from both eyes that allow perceiving the object as a whole and appreciates its depth, length, and width and discriminates the distance that exists between two objects. Normal stereopsis reflects the integrity of binocular vision [14].

Stereopsis was the greatest evolutionary development of visual perception (in human species and primates) that allowed adaptation to the environment [5].

31.4 How to Obtain a 3D Image [15, 16]

The traditional way to create a 3D image was taking two photographs from different angles, which simulated the way normal vision perceives depth of a scene. It can be done by taking a photo with a conventional camera and then taking a second photo simply by moving the camera slightly to the side; simulating the vision from two different points of view. This method only works if the object to be captured is static.

If the object to be photographed is in motion, a double camera configuration (twin cameras) is required so that both angles can be captured simultaneously. Two identical cameras mounted on a firm support are used and triggered synchronously. Due to the separation that is required between the lenses, it is not usually a good method for photos at very short distances.

Another more sophisticated system is the beam splitters (an optical device that splits a beam of light in two), which incorporates a system of mirrors or prisms in front of the lenses of an SLR camera. The final image of the object has two "parts", a right and a left image. There will then "two versions" of the photograph: a "right " image and a "left" image. Based on this concept, today there are different models on the market which make 3D photography like the ones in medical consultations.

Some examples of this equipment are the LifeViz camera Infinity models, Mini, Micro, or Body of the brand QuantifiCare (Fig. 31.3) [17], or the Vectra H1, H2 line (handheld 3D imaging system), XT (3D face and body imaging system), or WB360 3D® (whole body imaging system) from Candfield® (Fig. 31.4) [18], among others, built for medical professionals. For example, for a face in 3D photo using Vectra System®, three photos are taken (one from the right side, one form the left side, and one frontal. Each image is a stereoscopic image (as if seen by the right and left side). In post-processing, stitching of the three images generates a 3D final image. On the other hand, we also have large commercial photographic equipment houses such as Fujifilm, Sony, or Panasonic, which create digital cameras for 3D photographs, which can then be visualized on digital screens or televisions of their own brands.

31.5 Mechanisms of Vision in 3D

Let us review the different mechanisms of 3D vision [19]:

31.5.1 Parallel Free Vision (Side by Side Parallel)

Two images are placed one next to another, with each image located in front of the corresponding eye. The distance between the centers of the photographs should not be greater than the interpupillary distance (65 mm) to avoid divergence. One needs to look at a point in the infinity while trying to keep the optical axes parallel and then look at the images without altering the convergence, thanks to the accommodation of the lens. A third central image in relief and two blurry images on the sides will be created. It requires some training and patience [15, 16, 19].

Fig. 31.3 3D LifeViz® infinity (Courtesy of © QuantifiCare, All Right Reserved)

Fig. 31.4 (**a**) Vectra® H2, Handheald 3D Imaging System; (**b**) Vectra®XT, 3D Face and Body Imaging System (Courtesy of Canfield Inc., All Right Reserved)

31.5.2 The Cross-Free Vision (Side by Side Crossed)

This method consists of placing the right image of the left side and vice versa. To obtain the image, the person must squint (cross-eye) their eyes, crossing the optical axes. The centers of the images can be separated by more than 65 mm, but maintaining an ocular convergence no greater than 18°. When the correct convergence is achieved, a central image with relief and two blurred side images will be obtained. This technique produces ocular fatigue [20].

Stereoscopy is not believed to be harmful and cause visual disturbances [1, 2, 5–7], and it is even used for the treatment of binocular disorders. However, keeping your eyes crossed can cause discomfort and eyestrain. The quality of each stereogram can also significantly affect the understanding of 3D structure and visual comfort [20].

31.5.3 Anaglyphs

Based on the phenomenon of synthesis of binocular vision, an anaglyph consists of an image achieved by encoding each eye's image using filters of chromatically opposite colors. The relief is achieved by observing the image with glasses of complementary colors such as red-blue, red-green, or amber-blue. When viewed through these glasses, each of the two images reaches the eye it is intended for. The visual cortex fuses these images and perceives a 3D image. It is an economical and easy method, but it can present alterations in color and light, besides generating ocular fatigue [15, 16].

31.5.4 Polarization

Two images are projected with polarized light filters, which have opposite polarity (90°). In the case of linear polarization, an image is projected with the polarized light in the vertical direction while the other in the horizontal one, each being captured by a lens with the filter of the same direction. In the case of circular polarization, the images are projected clockwise or counterclockwise [15, 19].

In this technique the images are projected with two projectors with filters perpendicular to each other, or with a projector that emits the images alternating polarization planes by means of a multiplexer [19]. The spectator capturing the image uses glasses with lenses with opposite polarity; it is a method that is economical with good color quality, but has a limited resolution.

31.5.5 Alternative (Active Stereo)

In this system, the right and left images are alternatively projected. Liquid crystal shutter glasses need to be used which allow the passage of light or become opaque at high speed, intermittently for each eye. It is done through wireless signals between the glasses and the projector, which require synchronization. Better-quality images are obtained, but it is an expensive system. It is the method used in theaters and XpanD 3D technology [15, 16].

31.5.6 The Helmets (Head-Mounted Display, HMD)

It is a stereoscopic helmet that carries two screens and optical systems for each eye, so that the image is generated by the device itself. Its main use has been in virtual reality. Its disadvantage is its cost [16].

31.5.7 Auto-Stereo Monitors

They are prototypes of monitors that do not need special glasses for visualization; they use variants of the lenticular system. They are micro-lenses in parallel and vertical arrangement on the monitor screen, which generate a certain deviation from two or more images (usually from two to eight). They are still in technological development [16].

(a) *Parallax barrier*: an image is emitted with a vertical grid of opaque material, with regular spacing, which allows each eye to see an image with different perspectives that alternate, but are projected simultaneously. In this way the grid selectively interrupts the beam of light that corresponds to each eye.

(b) *Lenticular sheet:* based on the same concept as the previous one. The lenticular sheet is formed by cylindrical lenses (plastic substrate) in front of the image, which allow each eye to focus a line of sight according to their perspective. Examples of this system are the Nintendo 3DS screens.

31.5.8 Autostereoscopy or Autostereograms

They allow visualizing an image with relief without using any device. It is a composition where the three-dimensional object is projected for each eye, and the rest is composed of a repetition of small randomly generated patterns. When the brain detects changes in patterns, the whole is appreciated. It is a technique that can be difficult for many people; in addition, it can cause eyestrain [15, 16].

31.5.9 Pulfrich Effect

Pulfrich effect, discovered by the German doctor Carl Pulfrich in 1922, is the phenomenon which consists on the perception of a stereoscopic effect when an image is observed in horizontal movement on a plane and with a dark filter located in front of one of the eyes. Thanks to the lower luminosity perceived by the eye with the filter, the image reaches the brain with a delay of a few hundredths of a second, which generates the stereoscopic effect (delayed frames). It is not properly a stereo visualization system, since it does not originate from a pair of images but from a single animated 2D image [15, 16].

31.5.10 Chromadepth

The ChromaTep™ system from ChromaTek Inc. is based on the deviation produced by different colors, when light passes through a prism, and it is wavelength dependent. The glasses specially designed to see these images have transparent crystals with micro-prisms. When the image, called CyberHologram™, is seen with the HoloPlay™ (for computer images) or C3D™ (for printed images), the 2D image becomes three-dimensional. The disadvantage of this system is the loss of chromatic information, but the advantage over the anaglyph is that the images can also be seen in 2D [15, 16].

31.6 Three-Dimensional Photography in Medicine

In the medical field, the use of stereoscopy still is limited [20]. More studies need to be carried out with large samples of patients to allow standardizing the methods of use and anthropometric measures; however, there are more and more studies that incorporate the 3D image to assess the effectiveness of various treatments.

In the taking of anthropometric measurements, the 3D images provide precise measurements comparable to the manual images as referred in Ghoddousi et al. [21], being a very useful, fast, accurate, and noninvasive method to assess facial volume and racial characteristics [22].

Three-dimensional photography is becoming popular when evaluating the three-dimensional aspect of lesions such as stretch marks, hypertrophic and keloid scars, or wrinkles, where depth or thickness are very important to evaluate before and after treatments [23–26]; in tumors or vascular malformations [27], volume changes can be better monitored using 3D images, which provides much more information than conventional 2D images. This type of photography is becoming a practical, noninvasive, and safe tool that provides clear images [27, 28]. The opposite occurs with 3D hard tissue imaging systems (like the one used in bones) that have the problem of radiation [28].

The 3D imaging techniques are becoming more accessible, and the post-processing software is improving; doctors have the opportunity to work on these images, allowing them to plan and better predict treatment results [29]. The art of 3D design in computer science, the data provided by computed tomography (CT) and magnetic resonance imaging (MRI), preoperative surgical strategies, and evidence of postoperative results led to the concept of surgical simulation [14]. Surgical interventions or "navigation" inside the human body can be simulated as an aid to planning operations or for teaching. It allows surgeons to see the surgical three-dimensionally and learn and practice surgical techniques, increasing skills and precision in delicate operations, such as brain surgery [10].

An advantage of 3D systems is that all the entire surgical team can observe the procedure on a large screen, if equipped with glasses for stereoscopic vision [30]. The ideal 3D visualization free of the need to use special glasses is still under investigation [30].

These three-dimensional images of surgical interventions can be recorded in a conventional video to study them later or to be used in teaching [1, 31]. In the preoperative consultation, three-dimensional technology facilitates communicate results by creating surgical simulations with possible outcomes.

Teaching is an important area of medicine where 3D technology has obvious applications: in the visualization of samples and in the creation of multimedia virtual anatomy programs; it facilitates understanding and practicing of diagnostic and therapeutic procedures, reducing the curve of learning [32]. Techniques such as stereoscopic radiography allow locating foreign bodies or anomalies inside the patient [10].

Integrating imaging into forensic science provides a lot of relevant information and provides clues regarding the cause of a death, measuring size and shape of the body damaged, and preserving the visual information for longer periods [33–35]. Virtopsy is a simple and noninvasive procedure that gains more and more followers. It is a digital autopsy that creates 3D imaging of the corpse without direct manipulation. This is particularly useful as it takes less time and it is a procedure more accepted especially when there exist religious or emotional concerns in regard to body manipulation [35].

Three-dimensional total body photography (TBP) (VECTRA WB360 3D® whole body imaging system) captures nearly the entire body surface to generate a movable "avatar" image of the patient's skin. It is ideal for distributed diseases like psoriasis and vitiligo and particularly useful in monitoring patients at high risk of melanoma and numerous pigmented lesions. It reduces registering time as multiple photographs are taken simultaneously by 46 cameras, and the images obtained are later stitched into a 3D full body image. Besides being time saving, it avoids photographing more than one area of the body, a disadvantage that happens in 2D total body photography where part of the skin are photographed repeatedly depending on the pose; for instance, a nevus on the side of the abdomen can be seen on both a frontal and a lateral photograph. This problem is spared when a full body 3D image is created.

31.7 Advantages of 3D Imaging in Medicine

- Allows observing body images that are closer to reality, identifying objects and structures and appreciate movements as well as measuring distances [19].
- Store the image for later analysis as well as modify certain aspects (like position) to better observe the "before and after" of a surgical or cosmetic procedure.
- Allows a better assessment of the whole body during a dermatoscopy, especially in areas of curved surface [18] favoring the early detection of malignant lesions and better monitoring [36].
- Gives a more realistic and in-depth vision, superior to normal 2D photographs.
- Facilitates teaching of medicine, especially those regarding morphology.
- Visualizes, locates, and assess pathological findings.
- In laparoscopic surgery, it improves perception of depth and minimizes dizziness and facilitates surgical planning and training [10].

31.8 Disadvantages of 3D in Medicine

- It is still in its infancy and requires validation in order to be used as a standard tool for facial and body maps [36].
- In the case of virtopsy, there is still insufficient data as compared to conventional autopsies [35].
- It requires more complex calibration techniques [19].
- For many systems, it still requires using special glasses; these are not accepted; in addition there is the requirement for special projection screens [10].

- The cost of these 3D image systems, the size of the equipment, and the use of special software imply training; this can be a dissuasive aspect [37].

31.9 Uses of 3D Image in Other Fields

The virtual reality techniques facilitate user's interaction with the computer, allowing the creation of stereoscopic images in real time, simulating a 3D scenario. There are many fields in which they are used, here are some examples:

Architecture: it allows visualizing structural details, and the virtual reality allows navigating within a building, before its construction. Early example is the Valencian architect Demetrio Ribes (Valencia 1875–1921), a passionate photographer, who used his stereoscopic camera Verascope to make several stereoscopic images of the Valencian architecture of the early twentieth century [38].

Plastic arts: as well as in architecture, the use of 3D photography is used for visualizing masterpieces and letting the viewer be part of the scene. Painter Salvador Dalí made stereoscopic paintings; his object book *Dix Recettes d'Immortalité* (1973) refers to stereoscopic vision as the Holy Trinity, with the right eye as the Father, the left eye as the Son, and the brain—the Holy Spirit [8].

Archeology: recreates buildings and cities of ancient civilizations and facilitates the restoration of buildings or monuments.

Automotive industry: visualizes vehicles using computer systems using stereoscopic glasses such as stereosgraphics or VRex [7].

Aerospace industry: simulates flights, ships, and operations in space.

Molecular engineering, pharmaceutical industry: 3D images helps in visualizing complex molecules during their design.

Cartography, geography, speleology: they are favored by the use of three-dimensional images, which provides the possibility of recognizing objects and depths [15].

Education: 3D images can be used in multiple areas of education, facilitating the visualization of structures and natural phenomena as well as favoring abstract reasoning of students.

31.10 Conclusion

Medical 3D photography is still in its beginnings; however, it promises to be a fundamental tool for the different areas of medicine: teaching, medical consultation, monitoring of medical conditions or treatments, therapeutic planning, and scientific communications will benefit from the application of the 3D images.

In the future we will have more and more versatile equipment, smaller, lighter, with direct visualization, and of high precision, to facilitate their manipulation and avoid visual fatigue; and they will be more and more affordable.

Conflict of Interests The author declares that she has no conflict of interests.

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32

Focusing, Depth of Field, and Plenoptic Photography

Arash Taheri

Contents

32.1 Introduction

Conventional photography captures sharp images of objects which are in focus. The objects within a given "depth of field," which is a field around the focus distance, may be reasonably sharp. The objects farther or closer to the camera than the depth of field are generally out of focus. A shallow depth of field can be used to focus on a subject and keep the other objects in the picture blurry. A deep depth of field can be used to have sharper images of the objects in the field that are closer or farther than the main subject to the camera.

Light-field digital photography (also called plenoptic photography) is a relatively new technology that can capture data regarding direction of rays of light entering the camera and construct a three-dimensional image of the subject. The user can see two-dimensional pictures on a computer screen with the ability to focus on different subjects in the picture after capturing the image. This option makes it feasible to have more objects in focus in the depth of field of the camera compared with traditional digital or film cameras.

In this chapter, we review the concept of depth of field in photography as well as new technologies used in this area, including plenoptic cameras used in modern digital photography.

32.2 Cameras Focusing in Photography

A pinhole camera was the first device used by humans to project an image of the world on a screen. A pinhole camera is easy to make and use.

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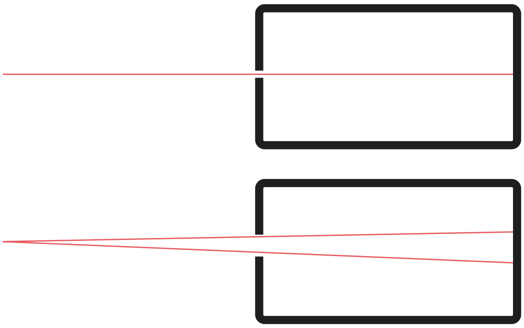

Fig. 32.1 Top: A small pinhole lets only one ray of light from each point on the world to enter the pinhole camera forming a sharp image of the point. Bottom: A larger pinhole lets more rays of light from each point to enter the camera forming a projected blur circle at the image plane. The resulting picture would be blurry

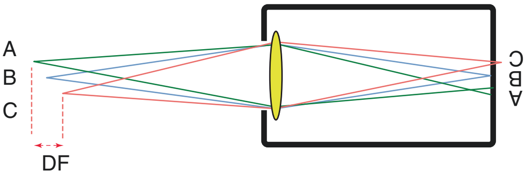

Fig. 32.2 In this camera, point B is in focus. Point A and C project small circles on the screen and are acceptably in focus. Distance between point A and point C is called depth of field (DF)

With an ideal pinhole, only one ray of light from each point in view can enter the camera, forming a sharp image of all of the objects in the field of the camera. A pinhole camera does not need focusing, because everything is in focus, no matter how far it is from the camera. The main problem with a pinhole camera is that the resulting sharp picture is very dim because a very small pinhole lets very little light to pass. A larger pinhole on the camera can let more rays of light from each point on the objects to enter the camera, forming a brighter image. However, the light does not form a sharp image of the object. Instead, a blurred circle, larger than the pinhole, is projected on the image plane from each point on the object (Fig. 32.1). To produce a sharp and bright image, a convex lens was used to concentrate the light rays from each point into a small point on the screen, forming a sharp and bright image of the object.

An ideal pinhole camera can make a sharp image of every point in front of the camera on the screen regardless of the distance of the point from the camera. However, when using a convex lens, an object relatively far from the lens produces an image relatively near to the lens, and an object relatively near to the lens produces an image relatively far from the lens. Therefore, a screen within a specific distance behind the lens can have a sharp image of objects at a specific distance from the lens. All other objects not within this specific distance will be out of focus. In order to have objects in focus, the photographer can change the distance between the screen and the lens (standard method of “focusing”) or change the lens all together.

A camera with a convex lens can precisely focus at only one distance at a time. The sharpness of the images of the objects not in focus decreases gradually on each side of the focused distance. The farther or closer the object is to the camera than the focused plane, the blurrier the image is. Within a given range of distance from the focused point, the lack of sharpness may be imperceptible. This range is called “depth of field.” Depth of field is the distance between the nearest object and the farthest object in a scene that appears acceptably sharp in the image (Fig. 32.2). Although there is a traditional arbitrary agreement on “minimum acceptable sharpness” and the “acceptable depth of field” written on camera lenses, this minimum acceptable sharpness may vary significantly depending on the use of the picture. A small screen such as a cellphone screen may need less sharpness than a large-scale professional screen or print. Therefore, the “acceptable depth of field” may vary depending on the use of the picture.

32.3 Depth of Field and Focusing in Modern Photography

The aperture of a camera is an opening in a camera lens that lets the light enter the camera. The size of this aperture can be changed to let more or less light to enter the camera. If the aperture is very narrow, then it acts similar to a pinhole camera with a deep (large) depth of field and a dim image. The wider the aperture, the more shallow (smaller) the depth of field (Fig. 32.3). The f-number (sometimes called focal ratio, f-ratio, or relative aperture) of a lens is the ratio of the lens focal length (the distance from the lens to the point over which initially collimated rays are brought to a focus) to the diameter of the aperture. A smaller f-number means a larger aperture, a brighter image on the image sensor, and a more shallow depth of field.

The main use of the aperture is to control the density of the light entering the camera. A large aperture is used in dim environments to capture more light from the objects into the camera. A small aperture may be used to control the density of the light in a very bright environment and protect the sensor from overexposure.

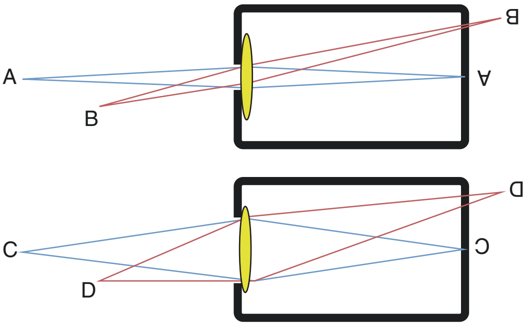

Fig. 32.3 Top: A small aperture provides a deep depth of field (DF). Image of point B is not as sharp as image of point A but is acceptable. Bottom: A larger aperture provides a more shallow depth of field. Image of point D is blurry

Changing the size of the aperture can also help with controlling the depth of field. In order to emphasize a subject while de-emphasizing the foreground and background, a small f-number (a wide aperture and a shallow depth of field) can be used to blur the images of the objects nearer or farther than the main subject (Fig. 32.4). Conversely, in order to have sharper images of multiple points or objects at different distances from the lens, the camera should have a deep depth of field. In this case, a narrow aperture (a high f-number) is used. Using a very small aperture to provide a deep depth of field needs very bright objects or environment. For indoor photography, supplementary light by a flash may be needed.

One problem with using a very small aperture (e.g., apertures smaller than f/16) is that it may bend the direction of the light rays entering the camera (called diffraction) and may negatively affect the sharpness of the image (Fig. 32.4). Therefore, a very small aperture increases the depth of field and improves the sharpness of the images of the objects that are out of focus; however it may minimally decrease the sharpness of the images of the objects that are in focus and are

Fig. 32.4 Left picture was captured with a narrow aperture (f:32). The middle finger is in focus, and the other fingers are relatively sharp (deep depth of field). In the right picture, a wide aperture (f:2.8) was used. The fingers that are not in focus are more blurry (shallow depth of field). The middle finger in the right picture is more emphasized. The hairs in focus in the right picture look minimally sharper than the hairs in focus in the left picture, because a very small aperture causes diffraction of light and affects the quality of the pictures

supposed to have very sharp images [1]. On the other hand, a nonprofessional lens with a very large aperture may cause aberration of the image and reduction in sharpness and quality of the picture [1].

32.4 Application of Depth of Field and Focusing in Medicine and Dermatology

Many physicians including dermatologists prefer their photographs to show more details regarding the patient by having the whole subject in focus. When taking a photo of a large dome-shaped skin tumor, one part of the lesion can be in focus, and the other parts may be out of focus and blurry. To have more parts of the lesion with reasonable sharpness in the picture, the photographers often use a narrow aperture to achieve a greater depth of field. However, as we discussed, a narrow aperture passes just minimal light into the camera. Therefore, to compensate for low quantity of light that passes this narrow aperture, they may use a brighter environment, a longer exposure time, or a higher sensitivity image sensor. An artificial light source may be used, but the small, built-in flashes on cameras are seldom ideal sources of light. A professional flash or light source is the best option but may be expensive, difficult to use, and not easily portable. Using a long exposure time is another option. However, a long exposure time (longer than 1/60 second) is associated with blurring of the image caused by movement of the camera or subject during exposure. A tripod can help to reduce camera shake; however, the subject cannot be fixed by anything. Increasing the sensitivity of the camera's image sensor, expressed in ISO or ASA, may help. However, very high sensitivities may be associated with lower picture quality in commercially available cameras.

Many physicians prefer to take pictures of their patients using automatic or "point and shoot" digital cameras or cellphones because they are fast and easy to use. While the autofocus systems may be quick, they cannot choose the main subject and decide about the depth of field. In certain situations such as photography of scalp lesions, an automatic digital camera with autofocus may not be very effective. When photographing the scalp, the autofocus mode usually detects the linear hairs as the subject to focus on, while the scalp itself may appear blurry. Therefore, the photographer may still need to choose the main subject to focus on and the appropriate depth of field. Some photographers connect their cameras to a large screen such as a tablet during photography to see a larger preview of their photo, to make sure that the main subject comes in focus with enough sharpness.

32.5 New Technologies and Future of Focusing

The photo-sensor of digital cameras detects the color and the intensity of light on each point (pixel) on the sensor and provides a two-dimensional image. A newer version of digital cameras called light-field cameras or plenoptic cameras captures data regarding the color, intensity, and direction of rays of light entering the camera. Having information regarding direction of rays of light, computer software can construct a three-dimensional picture of the subject or two-dimensional pictures with the ability to focus on different subjects in the picture after capturing the image. This option may make it feasible to take better images of subjects that are not easy to obtain in focus using conventional automatic digital cameras [2, 3].

The construction of a light-field camera is similar to a conventional digital camera except that light-field cameras use a microlens array in front of an image sensor and special hardware and software to capture data regarding direction of rays of light entering the camera. The resolution and quality of final pictures are dependent on front lens, microlens array, image sensor, and software. A detailed discussion of light-field capture is beyond the scope of this book [2, 3].

Light-field camera technology has enabled taking pictures without focusing. After capturing the image data, computer software is used to focus on specific objects in the picture. With this type of camera, every object in the picture potentially can be in focus. Typically, the software projects a two-dimensional picture on a screen similar to any other digital photo. Some object in this picture can be in focus and the farther or closer objects may be blurry. Then the user can scroll back and forth in the picture to change the focus and have the closer objects or the farther objects in focus. When the desired subject is in focus in the software and on the screen, the software lets the user save the picture as a conventional image file such as a JPEG file for printing or use on other software and computers. One can capture a photograph of the scalp using a light-field camera and then focus on either the scalp or anything else in the picture on the computer. The light-field camera is also very useful for photography of oral lesions, when the photographer wants to capture an image of the mouth from the lips to the pharynx and focus on the best point or points later. During endoscopic procedures, a light-field camera may take a picture that can potentially have all of the organs in front of the camera in focus. Therefore, the procedure can be faster and more informative.

Photography using a light-field camera is faster and easier than conventional photography, because there is no need to focus on anything with camera. However, resolution and quality of the final images of the available light-field cameras are currently lower than conventional digital cameras [4].

Light-field photography has been studied in dermatology, ophthalmology, and diagnostic and surgical endoscopic procedures, as well as medical education [4–9]. Although this technology has potential to replace the traditional methods of photography, it is not widely used in any field of medicine yet.

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Part VII

Preserving, Archiving and Publishing

Metadata and DICOM for Medical Photography

33

Liam Caffery

Contents

33.1 Why Metadata Matters

A clinical image by itself is useless unless there are associated metadata. At a very minimum, the patient who was the subject of the medical photograph needs to be known before the image can be used clinically. In this example, the patient's identifications (e.g., name, identification number, date of birth) are metadata attributes that may be associated with the clinical image.

Metadata are not specific to medical photography and are used to describe any information resource (e.g., document, textbook, journal, video, or website). Metadata, in the context of medical photography, is a set of text-based information that describes the image attributes (e.g., number of pixels) and/or related entities (e.g., the patient and/or the episode of care). An attribute is a discrete metadata item. For every image there can be many metadata attributes. Typically metadata are stored in name value pairs. The name (e.g., patient name) is a meaningful description of the metadata attribute, whereas the value (e.g., *John Citizen*) is instance dependent.

A metadata model is a document that lists all metadata items that are needed to describe an information resource. The model may logically group metadata attributes—for example, all attributes that are related to patient identity. Further, the metadata may also include rules about whether metadata attributes are compulsory or optional. Furthermore, a metadata model may contain rules about encoding of metadata attributes—for example, how dates are formatted. The purpose of a metadata model is to improve the standardization of metadata. The terms metadata schema, metadata model, and metadata definition are often used interchangeably. The

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metadata model can be in two documents. The first is a data dictionary which is a register of all available metadata attributes. In some instances, the data dictionary may contain the rules of optionality or encoding in lieu of the metadata schema. The second is a metadata schema which is used as a companion document to the data dictionary. A metadata schema is defined as, "a logical plan showing the relationships between metadata elements" [1, 2].

Medical photography metadata can be acquired at different stages of the image lifecycle, for example, the reason for imaging or a provisional diagnosis may be available at time of referral for imaging. Whereas, at time of acquisition, other metadata attributes that describe the pixel structure, or equipment or software used to acquire the image, are available. Post-processing of the image may add further metadata attributes (see Fig. 33.1). One such example of metadata being added during post-process is a wound-care system that adds wound morphology (measurements and wound appearance) resulting from user input as metadata attributes to wound photographs [3].

Metadata comes from multiple sources and multiple methods—for example, the acquisition modality will contribute metadata attributes such as the number and encoding of pixels. These attributes will be computer-generated. In the above wound-care example, the morphology attributes are manually entered into a computer form by an end user. Similarly, attributes such as patient demographics may need to be entered manually by the operator of the imaging device. It should be noted that the addition of metadata that require user input can be burdensome. Therefore, it is important the metadata collected be considered both in respect to usefulness and effort to collect.

The purposes of metadata in medical photography are many and are described in Table 33.1.

Ancillary clinical information such as pathology results, surgical reports, phenotypic information, or genotypic information is strictly speaking not medical image metadata. However, it is increasingly being referred to as metadata largely due the growing interest in artificial intelligence and the contribution this ancillary clinical information can contribute to image analysis and decision support. A recent whitepaper has proposed metadata elements to describe medical imaging data sets specifically for machine learning [11]. Suggested attributes include demographic, clinical, lab, genomic, timeline, and social media as ancillary clinical information that can contribute to machine learning.

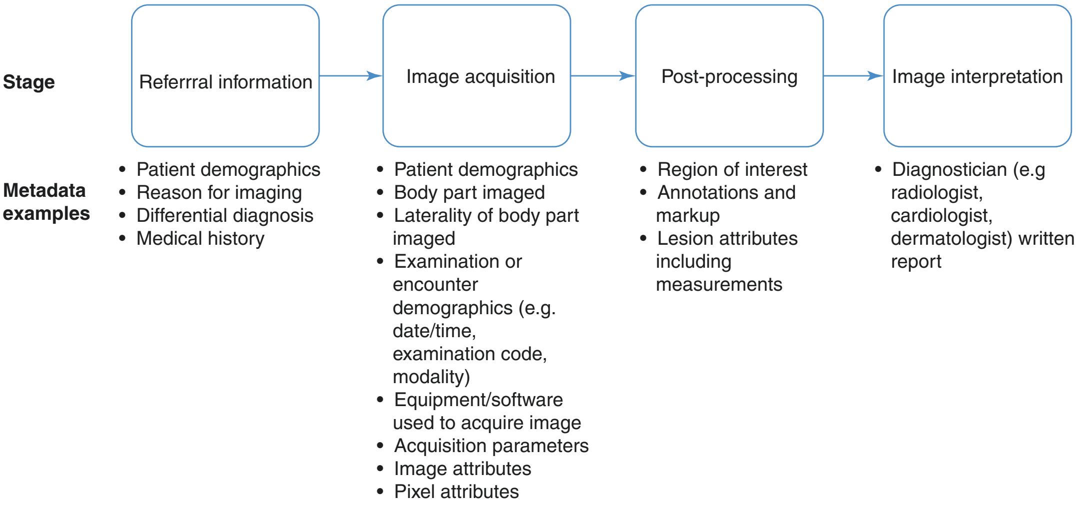

Fig. 33.1 Metadata attribute available at different stages of the image life cycle

Table 33.1 Purposes of image metadata

Identify the patient	As previously discussed one important use of the metadata is to identify the patient. Being able to identify the patient that was the subject of the medical photograph is paramount to patient safety and quality [4]. This is particularly important if the medical photograph is the catalyst for a medical procedure—for example, the excision and biopsy of a suspicious skin lesion [5]. Many healthcare organizations use multiple identifiers for a patient thereby decreasing the risk of incorrect patient identification. Resultantly, multiple patient identification attributes need to be stored as metadata. Typical patient identity attributes include patient name including given and surname, date of birth, gender, and unique patient identifier.
Identify the encounter or the imaging study	Patients will invariably have their care across multiple healthcare encounters. Imaging may occur on different encounters. Being able to identify the encounter or imaging study is particularly important with respect to sequential imaging and can be achieved using attributes such as a unique imaging study identifier or date of imaging. Sequential digital dermoscopy imaging (SDDI) is one such example. SDDI involves the capture and assessment of successive dermoscopic images moles separated by an interval of time [6]. The aim of SDDI is to detect changes in a mole over time. Changes are one marker of melanoma. Similarly, sequential imaging may be used to identify response to treatment for pressure ulcers [7] and burns management. Again, it is important to identify the encounter or imaging to observe changes over time. An imaging study may also be made up of a number of discrete images taken during the one encounter. These images can be linked into the one imaging study using a metadata attribute such as a unique study number.
Identify related images	Metadata can be used to link related images. In dermatological imaging it is considered best practice to take a regional image to demonstrate where on the body the skin lesion is located and a close up image to visualize the lesion in greater detail and resolution (see Fig. 33.2) [8]. In this example, the related images need to be viewed in conjunction with each other, and this is best achieved by linking the images. Having a metadata attribute that uniquely identifies each image and a second metadata attribute that stores the unique identifier of related or referenced images is one way that metadata can facilitate the identification of related images.
Safeguard patient privacy	Metadata can be used to assist in maintaining the patient's privacy. For example, the DICOM metadata model (discussed in detail later in this chapter) contains a number of metadata attributes (viz., *identifiable features* and *burned in annotations*) that are designed to help protect patient privacy. These flags are set to true if the patient's identity is recognizable from the photograph or annotations on the images. The flag can be used to exclude the image from teaching or research purposes. These attributes are only useful if used in conjunction with compliant software.
Diagnostic aid	Metadata attributes such as lesion characteristics, patient age, site of lesion, size of lesion, and laterality all assist with the diagnostic process. For example, a mole of greater than 6 mm is a clinical characteristic of melanoma [9]. Hence, in skin imaging it would appear beneficial to store lesion size as a metadata attribute or alternatively store pixel size as a metadata attribute to enable lesions to be measured using software [8]. A recent study looking at artificial intelligence compared the performance of computer-aided diagnosis of malignant melanoma from digital photographs. This study demonstrated the value of metadata in the diagnostic process. When simple metadata attributes (age, gender, lesion site) were included with image files both the sensitivity (95.2% vs. 82.1%) and specificity (91% vs. 86.1%) improved [10].
Store acquisition parameters	Acquisition parameters such as exposure, white balance, and flash can be stored as metadata. This allows reproducibility of imaging parameters with sequential imaging thereby improving reproducibility and consistency of images separated by time
Record image parameters	Image parameters refer to how the pixel data is encoded and stored in an image file. Metadata is used to record image parameters such as the matrix size (the number of rows and columns in an image), the photometric interpretation—for example, monochrome (grey scale), RGB (red, green. and blue image planes), or YBR (luminance [Y] and chrominance planes [CB and CR] that is used to encode JPEG images). A compression algorithm applied to the pixel data is needed to allow display software to correctly render and display the image
Indexing for storage, retrieval	Functionality such as searching an image repository is often reliant on the metadata stored within the image. Often, metadata is parsed from the images upon ingestion into the repository and stored typically within a relational database. End-user searches are translated into database queries and allow specific images or sets of images to be retrieved from the repository for viewing. Using this method images stored in repositories can be indexed by numerous attributes such as the patient identifier, patient name, date of imaging examination, study description, body part of images, and modality of imaging
Lifecycle management	Lifecycle management is an automated or semi-automated archive process the can be used to delete images in a repository over a certain age or alternatively move images over a certain age to a less expensive storage medium. The aim of lifecycle management is to facilitate the most efficient and cost-effective use of storage. Lifecycle management is reliant on stored attributes such as the study date to determine the age of an image

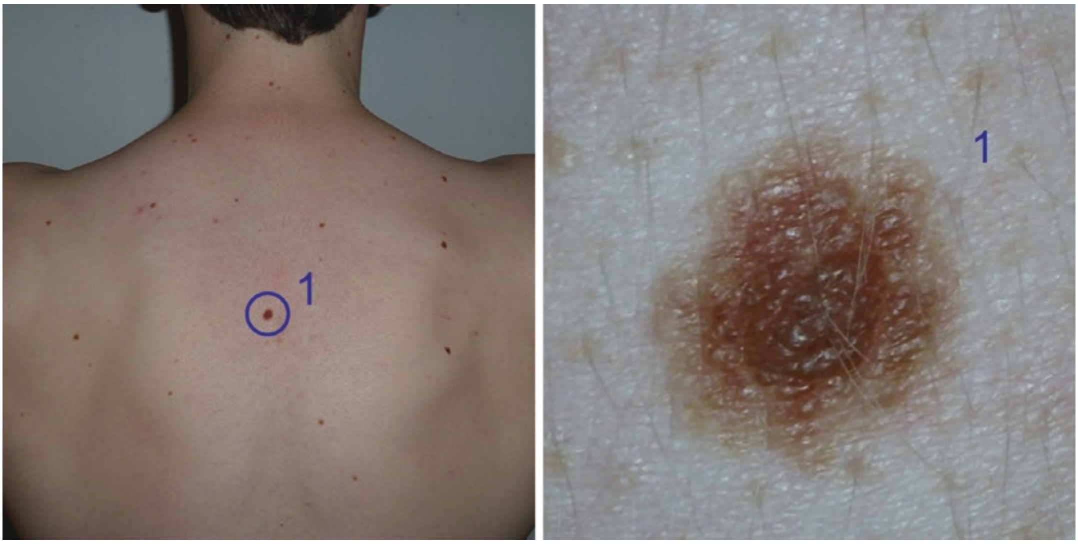

Fig. 33.2 Regional and close up image of pigmented skin lesion

33.2 Metadata Models for Medical Photography

Metadata can be encoded within an image file. This can be achieved in a number of ways including using medical imaging-specific file formats—for example Neuroimaging Informatics Technology Initiative [NIfTI] and DICOM. Alternatively, it can be achieved using consumer image file formats (e.g., JPEG, TIFF, PNG) that are employed in medical imaging but also have widespread application in other domains. What all of these file formats have in common is they store metadata amalgamated with pixel data in a single file. Further, they use a standardized metadata model. The metadata is most often stored at the beginning of the file in what is referred to as the file header. However, the categories of metadata can be different for each file format (see Table 33.2). Most notably, a consumer image file formats only include acquisition and image parameter metadata. Hence, they need to be used in conjunction with another actor—for example, an electronic medical record (EMR) or imaging modality—to store the patient and imaging examination metadata. To achieve this, a consumer image file is linked to a patient's chart or jacket within an EMR or integrated with dedicated medical image management software such as on an imaging modality [12]. One of the disadvantages is that EMRs and imaging modalities use proprietary as opposed to standardized metadata models.

Table 33.2 File formats and metadata categories

	Patient metadata	Encounter or imaging examination metadata	Acquisition and image parameter metadata
Consumer file formats			
Joint Photographic Experts Group (JPEG)	×	×	✓
Tagged Image File Format (TIFF)	×	×	✓
Portable Network Graphics (PNG)	×	×	✓
Medical imaging file formats			
Neuroimaging Informatics Technology Initiative (NIfTI)	×	✓	✓
Digital Imaging and Communications in Medicine (DICOM)	✓	✓	✓

Hence, the metadata implemented by an EMR or medical image management software or acquisition modality vendor may or may not be accessible via a standard application programming interface (API) [12]. DICOM would appear to provide an advantage over using consumer image file formats or other medical imaging file formats as it includes all the patient, study, and technical metadata necessary to use images clinically [12].

33.3 DICOM

33.3.1 Background

DICOM is an international standard to transmit, store, retrieve, print, process, and display medical images [13]. As a standard, DICOM is essentially a document that contains standardized specifications such as a metadata model, a file format, and commands to invoke actions (e.g., store, move, find) on the DICOM files. The actions are known collectively as DICOM network services. The standardized specifications are used by imaging device vendors and software developers to build DICOM compliant software that is used on medical imaging devices such as acquisition devices, workstations to display images, and repositories to store images. DICOM is the underlying information technology protocol in nearly every picture archiving and communication system (PACS) and vendor neutral archive (VNA).

The use of DICOM is almost ubiquitous in radiology, cardiology, and radiotherapy devices and is increasingly being used in specialties such as ophthalmology, dermatology, surgical and gastrointestinal endoscopy, as well as generic medical photography [14].

The DICOM standard development group is organized into working groups. A working group will develop a medical specialty-specific extension to the base DICOM standard. Using this process means that DICOM is continually being extended, enhanced, and updated.

DICOM is an open standard meaning any vendor can use it without any fees or royalties. The standard can be downloaded from the DICOM website either as individual parts (Table 33.3) or bulk download [13]. The DICOM standard is managed by the Medical Imaging and Technology Alliance which is a division of the National Electrical Manufacturers Association (NEMA).

DICOM is the common language that allows different categories of medical imaging devices from different manufacturers to exchange images and metadata. Hence, DICOM is an interoperability standard. Interoperability is the ability to syntactically and semantically share metadata and images across different devices in a medical imaging network. Syntax ensures the information is physically exchanged, and semantics ensure the exchanged information has a consistent meaning on both the source and destination device.

Table 33.3 Parts of the DICOM standard

DICOM Part 1: Introduction and Overview
DICOM Part 2: Conformance
DICOM Part 3: Information Object Definitions
DICOM Part 4: Service Class Specifications
DICOM Part 5: Data Structures and Encoding
DICOM Part 6: Data Dictionary
DICOM Part 7: Message Exchange
DICOM Part 8: Network Communication Support for Message Exchange
DICOM Part 10: Media Storage and File Format for Media Interchange
DICOM Part 11: Media Storage Application Profiles
DICOM Part 12: Media Formats and Physical Media for Media Interchange
DICOM Part 14: Grayscale Standard Display Function
DICOM Part 15: Security and System Management Profiles
DICOM Part 16: Content Mapping Resource
DICOM Part 17: Explanatory Information
DICOM Part 18: Web Services
DICOM Part 19: Application Hosting
DICOM Part 20: Imaging Reports using HL7 Clinical Document Architecture
DICOM Part 21: Transformations between DICOM and other Representations

Note: DICOM Part 9: Point-to-point Communication Support for Message Exchange and DICOM Part 13: Print Management Point-to-point Communication Support have been retired

33.3.2 DICOM Metadata Models

As previously discussed, one component of the DICOM is a standardized metadata model. The DICOM metadata model is called an information object definition (IOD). There is a different IOD for each type of medical image (e.g., digital photograph, microscopic image, endoscopic image, retinal image, CT scan, etc.). This is because while there may be common metadata attributes (e.g., patient metadata), there is modality-specific metadata that only needs to be defined in the relevant IOD.

Every IOD is based on a DICOM real-world model (Fig. 33.3) [15]. In the real-world, a patient will have one or more imaging studies. An imaging study may be performed on a different date or time, or be a different imaging study type. For example, retinal imaging and slit-lamp imaging (on the same patient) would be separate imaging studies even if they were performed on the same day. Each imaging study has a number of series. Series are discrete parts of the same imaging study. Some examples to highlight the concept of a series are:

- A CT scan contains a series of images acquired before and again after the administration of contrast medium.
- A dermoscopy examination of a pigmented skin lesion contains images of the lesion

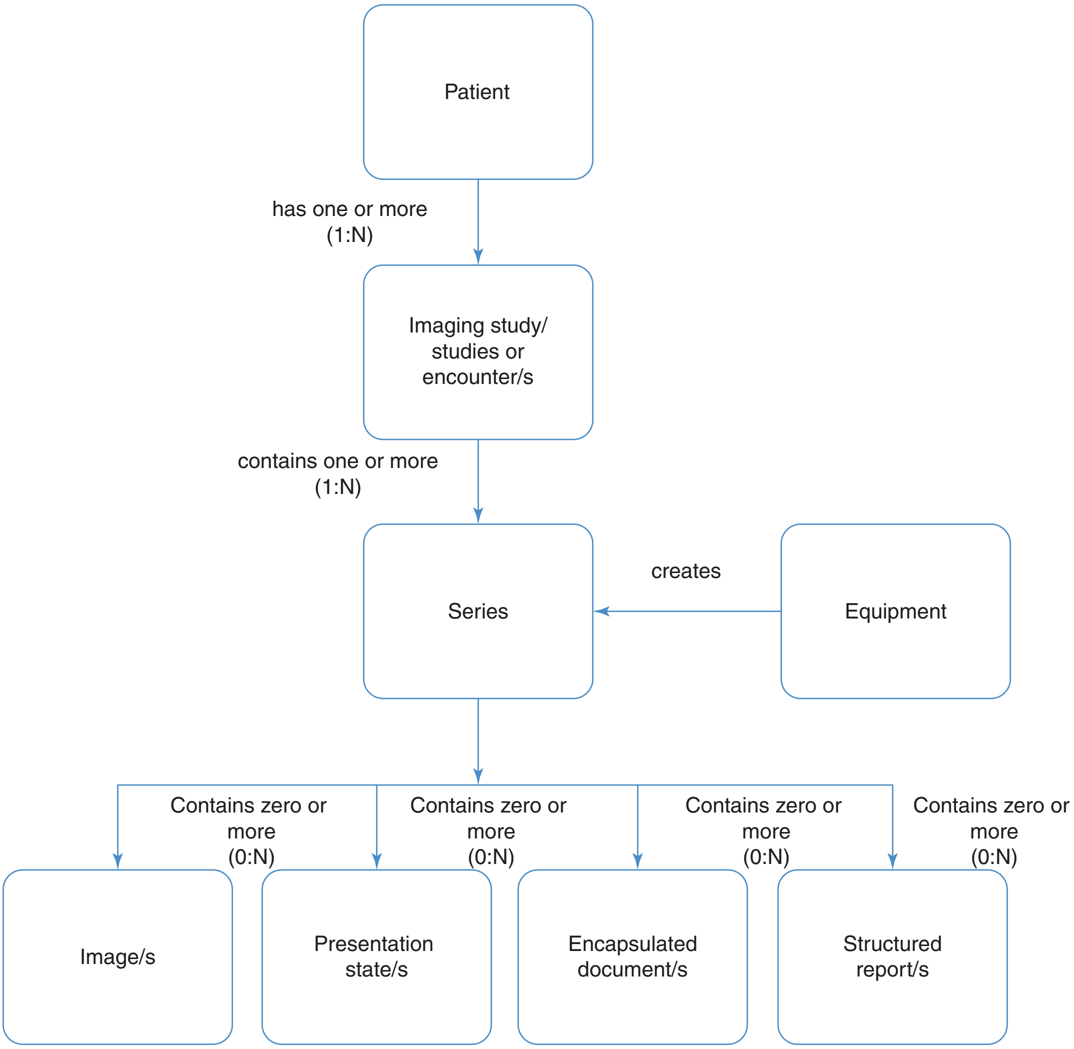

Fig. 33.3 DICOM real-world model

acquired under white light and again under cross-polarized light.

- A slit-lamp examination of the eye contains one series of images when the patient's gaze is looking up and another when the patient's gaze is looking down.

A series contains zero or more objects (e.g., image, presentation state, encapsulated document, or structured report). Each of these DICOM objects is described in Table 33.4. In practice, each DICOM object in an imaging study results in a discrete DICOM file being created. These files are linked by metadata attributes, namely, a series of unique identifiers.

The DICOM real-world model is made up of a number of entities—patient, imaging study, series, equipment, and one of the following—an image, presentation state, encapsulated document, or structured report. Each of these entities has what is known as a normalized IOD. The metadata in a DICOM object file is called a composite IOD as it contains multiple normalized IODs. For example, a DICOM image object will have metadata for the patient, imaging study, series, and image entities whereas, a DICOM structured report object will contain metadata for the patient imaging study, series, and structured report entities.

In medical photography the visible light (VL) IOD is the most common DICOM IOD. VL specifies images that are acquired by means of a camera or other sensors that are sensitive to visible or near-visible light. A VL object may be acquired by a digital camera, endoscope, microscope, dermoscope, colposcope, retinal camera, or slit-lamp camera [15].

All IODs defined by the DICOM standard are listed in DICOM *Part 3: Information Object Definitions*. DICOM *Part 6: Data Dictionary* contains a registry of all DICOM attributes including a group and element number to uniquely identify each attribute and rules about encoding the attribute (e.g., date format).

33.3.3 DICOM File Format

The most common DICOM file is an image and is described in Table 33.4. DICOM *Part 10: Media Storage and File Format for Media Interchange* describes encoding rules for creating DICOM files. The DICOM file format ensures

Table 33.4 DICOM objects

DICOM object	Description
Image	The most common DICOM object is an image. A DICOM image contains the metadata (structured according to the relevant IOD) and the pixel data to be merged into a single file. The pixel data is encoded using JPEG or other standard image encoding.
Presentation state	A DICOM presentation state object contains post-processing parameters. A presentation state can be linked to a single image or a series of images. The presentation state may contain text annotations or markups (e.g., region of interest, measurements) or changes to how an image is displayed (e.g., window and level). DICOM viewing software will first display the original image file and subsequently apply the changes contained in the presentation state.
Encapsulated document	In a similar way that a JPEG image file can be amalgamated with metadata to create a DICOM image, a portable document format (PDF) or text document can be amalgamated with metadata to create a DICOM encapsulated document. Encapsulated documents are linked to related image files (and other DICOM objects). Encapsulated documents can be used to store referral information, consents, worksheets, or diagnostic reports.
Structured report	A DICOM structured report (SR) is a DICOM object that contains text-only information structured according to the relevant SR IOD. It can be thought of as the metadata only. SR are often used to store diagnostic reports (e.g., a radiologist's interpretation). However, SR are not limited to interpretation and can be used to store any medically related textual metadata in a standardized format that facilitates interoperability. In ophthalmology, SR are used to store refractive measurements, optic nerve head analysis, and macular grid measurements. In radiology, SR are used to store radiation dose resulting from a radiographic procedure [2]. DICOM SR are linked to other relevant DICOM objects (most often images) and are intended to be viewed together. These objects are linked by metadata attributes.

there is no separation of the image and the metadata and contributes to the portability of metadata. If a DICOM image is transmitted from one device to another, the metadata is transmitted in the same transaction by virtue of the file format. This allows the metadata to be re-used on the destination device. This is advantageous in the following scenarios:

- An acquisition modality that acquires images in DICOM format can electronically store images and metadata directly to a DICOM-based image repository.
- A DICOM object can be transmitted from one storage device to another to mitigate end-of-service-life for a storage device.
- DICOM objects (e.g., image and encapsulated document containing patient history) can be transmitted from one organization to another to facilitate a telehealth consultation.

The same outcome is not easily achievable using consumer image file formats as the patient demographic metadata would need to be transmitted in a separate transaction to the image file. As previously discussed, this may or may not be achievable and is dependent on the availability of an API to access the patient demographic metadata. Furthermore, even when accessible the patient demographic metadata would need to be converted to a standardized format that can be used as a common language between the communicating devices.

33.3.4 Image Acquisition

Many dedicated medical image devices can natively acquire images in a DICOM format. The number of DICOM-compliant image acquisition devices is increasing proportionally with the increasing adoption of DICOM into non-radiology medical imaging specialties. However, it should be noted that not all of the acquisition devices support DICOM network services which gives them the ability to electronically store images to enterprise image repositories (EIRs) [16].

There are an increasing number of cameras that can support DICOM acquisition [17–19]. These can be apps that run on mobile devices or Android ™ cameras. Alternatively, they can be single lens reflex cameras that allow interchangeable lenses including dedicated medical lenses (e.g., dermoscope). Many of these cameras support worklists which allow the automatic retrieval of patient demographics from a patient master index, EMR or other computer system by either a query based on the patient identification number or barcode. Acquired images can be uploaded to an EIR using DICOM network services where they can accessed using links in the patient EMR [20].

There are also several options for converting consumer file formats into DICOM files. Import software applications can amalgamate a consumer file format from an attached device (e.g., digital camera) or file store location with demographics populated with an electronic form to create and store a DICOM image [21]. Alternatively, some DICOM web servers allow consumer image files to be uploaded with identifying metadata in an accompanying text file. The content of the image file and the metadata files are transcoded into DICOM format on the server [12].

33.3.5 Archiving Metadata

From the previous section, we have seen that metadata are often encoded in an image file. The image file needs to be archived. Archiving an image (and associated metadata) means it will be retained in a functional format to meet both the clinical and legislative requirements. Medical images and metadata are acquired to assist with the diagnosis and management of clinical conditions and as such need to be readily available to the treating clinicians. Healthcare providers are also under legal obligation to retain medical records. Different jurisdictions may have different requirements governing the length of retention [22]. The length of retention may also be conditional on the health service that was rendered, or the disease process of the patient.

Medical image retention generally conforms to the same the rules as medical records. This means that medical images (and their associated metadata) often need to be stored for 7 years or more.

Seven years are beyond the effective life of most information technology (IT) devices—for example, acquisition modality or storage devices. This gives rise to two important considerations for medical image retention. Firstly, the storage device needs to be fault tolerant to guard against hardware failure, and secondly, migration of the image (and metadata) from one storage device to another is a near certainty during the lifecycle of an image.

It cannot be guaranteed that an IT device will be free from faults and their effects during its operational lifetime [23]. For this reason, fault tolerance needs to be built into image repositories to mitigate effects such as data loss or failure of a component or a system. Redundant array of independent disks (RAID) is a fault tolerant storage system used in most image repositories and other archive storage. Data is stored across a group of hard disk drives. If one of these disks fails, it can be replaced, and the data that was originally stored on the disk can be automatically recovered from other disks in the RAID set. Another way of guarding against data loss is the use of disaster recovery (DR) storage systems. DR duplicates the data storage on a device that is geographically separated from the original storage device. This mitigates risks such as fire and flooding. The DR storage system often uses cheaper storage mediums—for example, magnetic tape storage or lower specification hard disk drives to reduce the cost of owning a DR system.

Migration of data from a storage device prior to the end-of-service life is another way of proactively managing a repository and mitigating faults in the storage system. In many imaging systems, data is often stored on the imaging modality. Migration from the imaging modality and/or image repository should be considered. Data migration can be more easily achieved if the metadata is in DICOM format as opposed to a proprietary database [24].

33.3.6 DICOM Image Repositories

Healthcare organizations have long used picture archiving and communication systems (PACS) as image repositories. More recently the vendor neutral archives (VNAs) have begun to replace PACS. What all these repositories have in common is they use DICOM as the underlying storage and communication protocol. Further, they are designed for fault tolerance and disaster recovery as described in the *Archiving metadata* section above. The difference between PACS and EIRs is essentially a change in architecture where the image repository is decoupled from the rest of the PACS (e.g., workstations for viewing images). Vendor neutrality refers to the fact PACS and EIR vendors can be different. Decoupling of the acquisition, storage, and display layers of an imaging network can be achieved when DICOM is the common language between these layers. For further explanation, see the interoperability discussion in the DICOM *Background* section above.

The evolution of PACS to EIRs has been driven by the increasing number of medical specialties that acquire digital images and by the growth in the use of EMRs. In particular, the desire to centrally archive images regardless of which department acquired the images, as well as the desire to have a single interface between image repositories and EMRs. This is known as enterprise imaging. Enterprise imaging is defined as "a set of strategies, initiatives and workflows implemented across a healthcare enterprise to consistently and optimally capture, index, manage, store, distribute, view, exchange, and analyse all clinical imaging and multimedia content to enhance the electronic medical record." The advantages and disadvantages of EIRs as compared to PACS are shown in Table 33.5 and were adapted from Caffery et al. [16].

33.4 Further Considerations

When used as a metadata model, DICOM provides many advantages over other options. However, there are still quite a number of imped-

Table 33.5 Advantages and disadvantages of enterprise imaging repositories

Advantages	Disadvantages
• Economies of scale of hardware • Economies of scale of staff resources to manage • Standardized metadata • Facilitates migration of images at hardware end-of-life • Avoids vendor "lock in" • Improves compliance with legislative requirements of image/medical record retention • Management efficiencies, e.g., single backup, business continuity plan and disaster recovery • Single point of integration for image sharing with EMR • Improved image sharing (inter-department, inter-organizational)	• Complexity of implementation • Appropriate access control to sensitive images, e.g., nude photos during total body photography

iments to the use of DICOM which need to be considered. DICOM has not defined IODs for many types of imaging that are being used in clinical practice—for example, the definition of dermatology-specific IODs is immature [12]. Until such IODs are defined more generic IODs (e.g., secondary capture IODs) could be used in their place [16]. Alternatively, vendors have the ability to add proprietary attributes to a metadata model. However, this impacts interoperability.

While there has been successful uptake of DICOM in some areas, other areas have been less successful—most notably the use of DICOM presentation states for recording markups and annotation and the use DICOM structured reports. Many vendors have implemented proprietary methods of image annotations and markups and in practice, DICOM SR are considered underutilized due to limited vendor uptake [11].

It should be noted that the standards development processes inherent in an international standards organization coupled with vendor adoption of new parts of the DICOM standard and product lifecycles can lead to considerable time in having new IODs used in clinical practice. This naturally leads healthcare organizations to seek solutions that can be implemented immediately. One such option is storing images within the EMR as opposed to in an image repository.

33.4.1 Storing Clinical Images in the EMR

Most major EMR vendors have a mobile device app that allows the capture of images using the device's camera and uploading of the images to the patient's chart [25]. The app is configured in a client-server architecture allowing access to a limited version of the EMR. Typically images are captured at point-of-care using digital photography. The end user can access patient demographics in a manner analogous to using a worklist. Additional metadata attributes such as the anatomical site can be added prior to acquisition via the user interface. Acquired images are stored directly into the patient's chart in the EMR in a consumer file format. The obvious advantages are the ease of implementation and the streamlined workflow. However, issues such as the proprietary metadata model and the portability of both metadata and imaging remain.

33.5 Conclusion

In medical photography the importance of metadata may not be apparent; however, metadata is essential to ensure the clinical utility and management of images. The functions of metadata are to identify the patient, to facilitate sequential imaging diagnosis, to improve reproducibility of sequential imaging by storing acquisition parameters, to link together related images, to link together related objects (e.g., images and documents), to record image parameters, so display software can correctly render the image, and to index the image for storage and retrieval in a repository.

There are a number of options for storing metadata; however, DICOM would appear to provide an advantage over using consumer image file formats or other medical imaging file formats as it includes all the patient, study, and technical metadata necessary to use images clinically. Further, it means the images and metadata are interoperable and portable. The use of DICOM for metadata would allow other components of the DICOM to be leveraged. For example, all images could be managed centrally in an EIR including linking the images to the EMR, so referring clinicians can have one patient-centric view and access to images regardless of which department the images were acquired. There are limitations to DICOM that should also be considered.

Acknowledgment *Disclaimer*: Companies and products mentioned in this chapter should not be taken as an endorsement. Liam Caffery is not affiliated in any way with any of the companies mentioned in this chapter and he does not receive any financial gain from any of these companies.

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Coding and Reimbursement

34

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Contents

34.1 The US Scenario

In modern medicine, digital photography is widely used. Photographs and imaging procedures may readily be taken during clinical evaluations. Images may be stored as part of a patient's electronic medical record (EMR) and can be very useful in evaluating the response to a specific treatment. Images also provide a deeper insight into a patient's medical history. Having images in the EMR allows a physician to get a more detailed picture of the clinical process [1]. Storage of photos in the EMR also facilitates the exchange of images between providers which has been shown to improve patients' care and satisfaction while reducing the number of unnecessary procedures, especially when those procedures were performed by another physician [2, 3]. Images can be used outside clinical purposes as integral components of scientific publications, research, and educational materials.

While the utility of clinical images is indisputable, there may be barriers to obtaining them, as clinical photography requires the physician to have basic photographic knowledge and skills. Furthermore, taking clinical photographs may prolong the duration of the encounter when accounting for the time needed to consent the patient for photography, capture the actual images, and then store and label them. Naturally, medical professionals have raised and discussed the question of reimbursement for the additional time required.

Reimbursement for medical services and procedures in the USA is a complex topic. Payment for government-insured patients (i.e., those over 65 years of age on Medicare and disabled or low-income individuals on Medicaid) is determined by the Centers for Medicare and Medicaid Services (CMS). Since 1992, payment has been

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based on a resource-based relative value scale (RBRVS), and the cost of a service includes the physician's work (usually 50.9% of a service), practice expenses (44.8%), and cost of liability insurance (4.3%). Physicians from different specialties and professional societies participate in the decision-making through the Relative Value Scale Update Committee (RUC) that consists of 31 volunteer physicians and 300 medical advisers from different specialties. The RUC regularly reviews all procedures and suggests if reimbursement for the services is appropriate, though CMS makes the final decisions.

Currently, over 10,000 current procedure terminology (CPT) codes exist and have relative values, measured in relative value units, pure numbers which are multiplied by an annually determined conversion factor which is valued in dollars, which are annually updated [4]. The most common codes, called category I codes, are part of this system. Category III ("tracking" codes) are discussed below. Most private insurance companies follow the lead set by CMS and use the RBRVS to set values. They also often agree with the government's determination as to whether a service is "medically necessary" and consequently whether they will pay for it.

Images obtained during diagnostic procedures (e.g., radiological images such as computer tomography or ultrasound) do not have additional reimbursement, as they are obtained and stored by computer equipment and are already an integral part of the procedure. Furthermore, there is no additional reimbursement for using an EMR though incentives to use one have been part of the government's mandate since 2010 [5]. The creation of EMR systems that are easy to operate and allow for effortless, intuitive integration of images would undoubtedly reduce the burden on physicians and will hopefully be a part of future practice. There are already a few such systems that show promise.

At the time of writing this chapter, there is a proposal from the CMS for some dramatic alterations to documentation requirements with less focus on history and physical exam and more emphasis on medical decision-making [6]. In visual specialties, this would encourage physicians to spend less time capturing often redundant textual data and let images speak for themselves. For example, instead of a narrative description of distribution and severity of inflammatory dermatoses, a few photos would more accurately portray the patient's status. Whether the proposed changes will become law will not be known until December 2018 when the CMS final payment rule for the physician fee schedule for 2019 is issued.

In the USA, lifeIMAGE® for the EMR "Epic" is an example of a platform that allows the user to integrate photographs from imaging studies into the patient's record. In dermatology, clinical images of a patient are of paramount significance. Epic is a private company which targets institutions as their major customers and for most users a keyboard centric experience. Despite institutions buying a system that already has been built, it is expensive to customize. A quote from the New York Times article sums it up quite well. "On a really good day, you might be able to call the system mediocre, but most of the time, it's lousy," said Michael Callaham, the chairman of the department of emergency medicine at the University of California, San Francisco Medical Center, which eight months ago turned on its $160 million digital records system from Epic [7].

A few EMRs were specifically designed for dermatology (Modernizing Medicine's Electronic Medical Assistant (EMA), CureMD, CosmetiSuite, etc.). These EMR systems offer data entry from mobile devices such as smart phones or tablets through their applications (apps), have full body charts that enable drawing and describing the lesion location, and include the ability to integrate images that were captured using the mobile device's built-in camera, thus expending less effort on transferring and labelling images. Some such as modernizing medicine also have packages for other "visual" specialties such as gastroenterology, ophthalmology, orthopedics, otolaryngology, pain management, plastic surgery, and urology.

There are only a few procedures involving photography in medicine that are currently reimbursed in the USA. One such example is total body imaging (TBI)—added to the CPT category I codes in 2007—which is used to monitor pigmented lesions in patients with multiple dysplastic nevi or a personal or familial history of melanomas. Although the CPT code exists (CPT 96904, "Whole body integumentary photography, for monitoring of high risk patients with dysplastic nevus syndrome or a history of dysplastic nevi, or patients with a personal or familial history of melanoma"), its use is still limited because some insurance companies do not cover it. CPT code 96904 is considered a "practice expense"—only code as the physician work of evaluating the images would be considered part of a separate, face-to-face cognitive, reimbursable service. The imaging is typically performed by a non-physician employee. Some insurers may reimburse for TBI to be performed annually in patients meeting certain criteria. The TBI code and codes in general were created to allow coverage of typical activities and not to encourage the use of a particular device or regimen. Although multiple devices and computer programs exist to perform TBI, the reimbursement is the same. Multiple scanning devices (MoleMapCD, Fotofinder Dermascope, Molemax II, VideoCap 100, etc.) are commercially available for TBI, but their cost and obtained results vary [8, 9].

Dermoscopy (also known as dermatoscopy) imaging may be used in addition to TBI but does not increase reimbursement. Dermoscopy uses a non-invasive magnifying device to identify structures of the lesion that are not identifiable by the naked eye alone, facilitating the early detection of skin cancers. Used by many dermatologists on a daily basis, its use has become a common part of the skin examination analogous to a stethoscope, otoscope, or ophthalmoscope, none of which allow extra reimbursement for their use [10]. In many countries (including the USA and Canada), there is no reimbursement for using a dermatoscope despite its proven benefit of allowing a more efficient and accurate diagnosis during clinical encounters [11]. At the same time, the cost of such a device is perceived as relatively high (up to several thousand dollars), and questionnaires showed that the lack of availability of the device was the leading reason why it was not used by some dermatologists [12]. Dermoscopy is reimbursed in some European countries (e.g., Austria), while others reimburse for skin cancer screening with the option to add an additional fee if dermoscopy is used [13, 14].

External ocular photography (CPT 92285, "External ocular photography with interpretation and report for documentation of medical progress (e.g., close-up photography, slit lamp photography, goniophotography, stereo-photography)")—is an ophthalmology-specific code and is used to document conditions of the external eye structures with a choice to track changes over time. As in TBI, no physician presence is needed to perform the procedure, and it may be done by a technician. The use of this code should be carefully justified to be covered by insurance. Similar to dermoscopy in dermatology, some ophthalmology imaging studies involve use of magnification lenses and imaging such as fundus photography (CPT 92250, "Fundus photography with interpretation and report") and ophthalmic biometry (CPT 92136, "Ophthalmic biometry by partial coherence interferometry with intraocular lens power calculation").

Telemedicine also frequently uses images, which may be sent to another provider for consultation or used in online communication between a patient and physician. Despite efforts to create a unifying system of reimbursement in telemedicine, legislation varies between different states. Three main types of telemedicine have been defined: live stream, store-and-forward, and remote patient monitoring, each with different reimbursement processes. Images of a patient or imaging studies are commonly sent electronically in the store-and-forward telemedicine model, which is currently reimbursed in only 13 states in the USA [15].

At present, the same codes used for face-to-face evaluation and management services can be used for telemedicine, with a suffix called a modifier addended to these codes. Modifier 95 should be added to the CPT code when the service is provided in real time and modifier GQ added for the store-and-forward services. Proposed changes by the CMS include paying for the following: virtual check-ins, evaluation of patient-submitted photos, and expanding Medicare-covered telehealth services to include prolonged preventive services [6]. A list of all codes that can be reported for telemedicine services is listed in the CPT

2018 code book in Appendix P, and this list is updated annually [16].

Some limitations may exist in different states and may limit reimbursement of telemedicine services to only rural areas or for certain medical conditions. As per communication with physicians working in private offices, some implement a fee-based system of reimbursement for telemedicine services based on patient preference (e.g., if the patient is unable to attend a follow-up visit and prefers to send an email containing clinical information or images). Often, such services are paid out-of-pocket due to the arduous process of claiming a reimbursement. Today each insurance company can decide whether or not to cover telehealth services. Such coverage is not widespread, though this may change if CMS makes the proposed changes effective January 1, 2019.

Reimbursement, or lack thereof, may limit the use of new imaging technologies that could potentially help in the prevention or early diagnosis of significant medical conditions [17]. Companies which develop new imaging technologies are required to perform large randomized control trials to demonstrate the utility of their devices in addition to lengthy approval processes and costly device marketing. As such, the overall cost of developing new imaging technologies is usually high and difficult to justify if reimbursement issues forego practicality. Nevertheless, some new technologies are successful in getting reimbursement. Recently, reflectance confocal microscopy (RCM) made it through the coding (CPT) and RUC valuation process with a Category I code that can be covered by most insurance payers (CPT codes 96931-96936).

While RCM is considered a standard procedure in much of the EU, uptake has been slower in the USA despite the development and valuation of these codes. Other procedures may get so-called Category III or “tracking” codes. The CPT process allows codes with less US-based evidence for the use of a technology that otherwise appears promising. The codes have a limited life and are potentially convertible to Category I codes if the appropriate criteria are met [18]. One such example is optical coherence tomography (OCT) or multispectral digital skin lesion analysis. “Tracking” codes have an added “T” to the code number (e.g., 0470T-0471T codes are used for OCT and 0400T-0401T for multispectral analysis).

New technologies have the potential to allow physicians to render a diagnosis more efficiently. It would be a shame if the uptake of such technologies were hindered by lack of reimbursement for their use. It is important to maintain awareness and engagement with emerging technologies in one’s field. Increasing the popularity of new imaging devices could lead to further studies on their significance and potential benefits (or contribution of relevant data). Once a particular specialty embraces novel imaging technology, appropriate CPT codes and reimbursements are more likely to follow.

34.2 The European Scenario

Most medical technologies are paid for by Public Health Authorities in Europe, usually within a third-party payer system in countries with a Bismarck model (Switzerland, France, Belgium, the Netherlands, and Germany). Great Britain, Spain, Italy, Scandinavia, and Finland adopted this model in the early 1960s, funded by taxes.

Indistinctly, each European market has its own unique characteristics: in some countries, budgeting and reimbursement decisions are made by regional authorities, while in others these are made at national level. Certain countries have separate systems for reimbursement for hospital and community care sectors, and the amount paid for services might differ even within a country. Among others, medical technology companies need to know what reimbursement and funding mechanisms are in place, what the requirements to obtain such reimbursements are, and what health authorities, patients, and citizens are willing to pay for. In the medical technology sector, this means understanding payment and reimbursement systems, local policy environments, and how healthcare systems are organized.

An example of success in national tax-funded health systems is teledermatology in Spain: in a survey published in 2015, teledermatology was reported to be used at 25 centers in 2009 and, later on, 70 in 2014. Store-and-forward teledermatology was the main technique (83%) in 2014. Only 12% of centers used the real-time method, and 5% used a hybrid modality. Patients lived less than 25 km away in 75% of cases (urban teledermatology). Most centers used mid-range bridge cameras; only 12% used mobile phones.

Teledermatology was restricted to skin cancer in 25% of cases, and 66% of centers used it to train primary care physicians. The main advantages, assessed on a scale of 1–10, were prioritization in cancer screening (8.3), rapid emergency care (7.8), training of and communication with primary care physicians (7.6), screening for trivial conditions (7.6), and reduction in the number of face-to-face visits (7.6). Between 2009 and 2014, the number of centers using teledermatology and the number of teledermatologists increased, as did use of the store-and-forward and urban models [19].

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35

Digital Imaging in Dermatology: HIPAA/PHI Rules and Compliance

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Contents

35.1 Background

Privacy is derived from the Latin, *privatus*, which means "restricted to use of a particular person." All physicians, in the course of caring for patients, become privy to knowledge that should not be shared with others, at least not without permission of the patient, and hence, this material is private. Likewise, patients must trust that images of their body, perhaps unclothed, or in states of disease, will not be shared with others in a manner that violates notions of privacy. Undoubtedly, concerns of privacy are replete in medicine, but, in dermatology, and other visual specialties where use of digital imaging is prevalent, concerns related to body image exist that are paramount. The interests of the patient and physician can be incompatible when it comes to privacy concerns. This article explores legal duties with respect to handing patient's digital images, as well as numerous examples and hypotheticals of potential privacy related issues.

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35.2 Controlling Law in the United States

Generally speaking, a patient's right to privacy can be divided in two categories: (1) the patient's right to protect certain medical information from the government and (2) the patient's right to protect certain medical information from the rest of the world. In the United States, "sources" of legal rights and obligations are numerous and include federal/state Constitutions, federal/state legislation, federal/state law created through lawsuits, and lastly federal/state administrative rules, regulations, and decisions. As such, when conducting a privacy analysis in the context of the physician/patient relationship, several sources of potential rights and obligations must be examined.

First, the US Constitution is the original source of rights and obligations in the United States. Although certain implicit rights to privacy exist in the Constitution [1], no express right to privacy is mentioned in the Constitution. Nonetheless, the US Supreme Court has acknowledged an *implicit* right to privacy in several key decisions [2]. These US Supreme Court privacy cases, however, are largely unhelpful in the patient/physician context.

Next, there are ten state constitutions—Alaska, Arizona, California, Florida, Hawaii, Illinois, Louisiana, Montana, South Carolina, and Washington—that have explicit provisions relating to a right to privacy, with an 11th state, Missouri, recently passing legislation regarding privacy in electronic transactions and communications [3]. Patients in these states are afforded an explicit constitutional right to privacy with respect to the transmission of digital images arising in the patient/physician context.

The controlling federal legislation central to the matter is the Health Insurance Portability and Accountability Act (HIPAA) of 1996. HIPAA, passed by the US Congress, was "designed to improve portability and continuity of health insurance coverage in the group and individual markets, to combat waste, fraud, and abuse in health insurance and health care delivery, [and] to promote the use of medical savings accounts, to improve access to long-term care services and coverage, to simplify the administration of health insurance," among other purposes [4]. HIPAA, in conjunction with a state equivalent, is the primary legal source of a patient's potential privacy rights.

The net effect of HIPAA was to establish standards for medical record keeping in the United States and to regulate the use and disclosure of medical records, including use of photographs/images obtained in the provision of medical care and medical research. As such, HIPAA seeks to balance the competing ideals of availability and confidentiality of medical records. A patient is not afforded a right to sue a physician for a HIPAA violation [5]. This is because no private cause of action exists under HIPAA. Instead, in order for a patient to prosecute a HIPAA violation, a complaint must first be filed under the established administrative procedures of the Office of Civil Rights of the Department of Health and Human Services (HHS), or a state equivalent.

The provisions of HIPAA were augmented by the Health Information Technology for Economic and Clinical Health (HITECH) Act of 2009, passed as part of the American Recovery and Reinvestment Act of 2009 [6]. HITECH was designed to promote the adoption and meaningful use of health information technology. HITECH expanded the duties of HIPAA protections to "business associates," to include data service providers and purveyors of electronic medical record databases. A recent HHS settlement underscores the importance of executing business associate agreements with entities that have access to protected health information [7]. In that case, a health-care provider was investigated for HIPAA/HITECH infractions after an employee of a business associate had an unencrypted, password-protected laptop containing patient information stolen from his/her car. The investigation uncovered the entities did not have a valid business associate agreement. The health-care provider experienced a $1.55 million penalty and ordered to participate in a corrective action program. This example drives home the point that a health-care provider can and will be liable for the misdeeds of a business associate without the proper protections in place.

HITECH also stiffened financial penalties for violation of HIPAA/HITECH rules, and it allowed states' Attorney General the option of pursuing claims against violators. Details of the so-called Omnibus Final Rule of HIPAA/HITECH, as promulgated by the HHS in 2013 [8], will be the basis for the discussion in the passages to follow.

The Supremacy Clause of the Constitution of the United States states that laws and treaties made pursuant to the Constitution, and the federal powers afforded within "shall be the supreme Law of the Land" [9]. While it is recognized that HIPAA and HITECH preempt state law that lies in conflicts with these acts, it is also recognized that state law that mandates additional privacy measures that exceed, but do not conflict, with HIPAA/HITECH is lawful.

HHS has stated that the protections afforded by HIPAA/HITECH, and other laws, represent a federal minimum; other governments and covered entities can create laws and regulations that exceed these minimum protections [10]. It is not possible in this concise review the detail the specific laws of the fifty states, but one must be cognizant that state, local, or even institutional standards may be more stringent than those established by federal law, and this does not automatically invalidate such measures.

35.3 Protected Health Information

As mentioned, HIPAA/HITECH regulates the use and disclosure of protected health information by covered entities, as well as their "business associates." This "protected health information (PHI)" is defined as [11]:

> [I]nformation, whether oral or recorded in any form or medium, that:

- is created or received by a health care provider, health plan, public health authority, employer, life insurer, school or university, or health care clearinghouse; and
- relates to the past, present, or future physical or mental health or condition of any individual, the provision of health care to an individual, or the past, present, or future payment for the provision of health care to an individual.

Table 35.1 Examples of protected health information covered in HIPAA/HITECH

- Names
- Geographic subdivisions smaller than a state
- Dates (except year) for birth date, admission date, discharge date, date of death, and all ages over 89
- Telephone numbers
- Fax numbers
- Electronic mail addresses
- Social security numbers
- Medical record numbers
- Health plan beneficiary numbers
- Account numbers
- Certificate/license numbers
- Vehicle identifiers
- Device identifiers and serial numbers
- Universal Resource Locators (URLs)
- IP address numbers
- Biometric identifiers, including finger and voice prints
- Full face photographic images and any comparable images
- Any other unique identifying number or code

On a more concrete level, PHI includes all of the information as listed in Table 35.1.

Similarly, "covered entities" include medical care providers, health-care clearing houses, employer sponsored health plans, and other insurers. A covered entity is responsible for training all members of its workforce on its privacy policies and procedures [12]. Additionally, a covered entity must establish and enforce appropriate sanctions against workforce members who violate policies and/or privacy laws.

- ***Illustrative Case #1***: Recently, a professional football player suffered a fireworks accident that led to an amputated finger, and this was disclosed via photographs of his actual medical record released on social media by a sports new purveyor [13]. There were immediate calls on the same social media, by lay-persons, demanding that the large commercial new organization and the reporter be punished for violating HIPAA/HITECH. What are the actual legal issues at play?

- ***Discussion***: There may be issues regarding the unauthorized release of information by the health-care employee who took the photograph of the medical record, and disclosed it to a reporter, but neither the reporter nor the sports news purveyor is a "covered entity" under HIPAA/HITECH. Legal action against these latter parties would involve claims of invasion of privacy versus freedom of the press and would not be made under the laws of HIPAA/HITECH.

35.4 Clinical Photographs/Images in Dermatology

Of the entities listed in Table 35.1 as PHI, the entry most germane to this article, and a ubiquitous concern in dermatology, is the concept of the "identifiable photograph." An "identifiable photograph" is regarded to be that of the face, or any other photograph that contains unique identifying information, such as a unique birthmark or custom tattoo [14]. Also, other recognizable persons in the photo, such as relatives, employers, or other household members, will render a photograph protected, even if the body parts of the patient proper are not identifiable. Similarly, the placement of a ruler, or similar item, labeled with the date, with patient initials, with a medical record number, or with any other link to the patient (see Table 35.1) also renders an otherwise unidentifiable photograph into protected heath information. Many clinicians forget that the date of service, patient initials, and the medical record number are all considered identifiers.

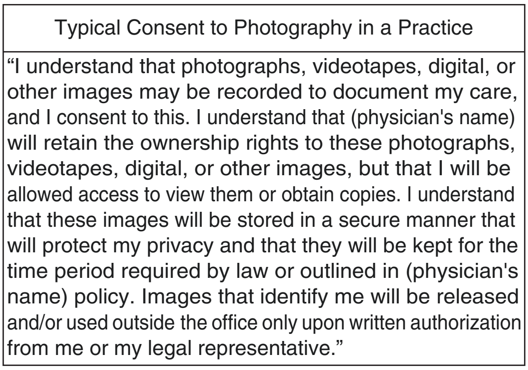
A photograph of a cutaneous lesion that does not include the face, and does not contain any other unique identifier, is not PHI, and is not subject to the same regulations of HIPAA/HITECH that pertain to PHI. By the same token, a *photomicrograph*, ubiquitous in dermatopathology, is not PHI, because it provides no identifying information at the macroscopic level. Dermoscopy images, also requiring a magnification source, are also not identifiable images at the macroscopic level.

While this is not a paper on technical standards, technical recommendations, or product configurations, if so-called metadata is attached to the image file, either by the camera or by software employed in storage, and if this metadata contains PHI (such as a patient name, a date of birth, a medical record number, or any other data contained or eluded to in Table 35.1), then that could also render the photo PHI [15].

Lastly, even if something is not PHI, for the reasons outlined above, it does not mean that journals, textbook publishers, or conference organizers cannot establish independent policies on images that ***exceed*** privacy protections afforded by law; as business entities and organizations, this is entirely within their prerogative.

35.5 Consent to Photograph/Image

It is well established that informed written consent is a valid defense to a claim of invasion of privacy [16]. In this regard, should one desire to use patient images for teaching, publication, or promotional purposes, it is simply the safe practice to obtain written informed consent for the express use(s) that is (are) desired (Fig. 35.1).



Typical Consent to Photography in a Practice

"I understand that photographs, videotapes, digital, or other images may be recorded to document my care, and I consent to this. I understand that (physician's name) will retain the ownership rights to these photographs, videotapes, digital, or other images, but that I will be allowed access to view them or obtain copies. I understand that these images will be stored in a secure manner that will protect my privacy and that they will be kept for the time period required by law or outlined in (physician's name) policy. Images that identify me will be released and/or used outside the office only upon written authorization from me or my legal representative."

Fig. 35.1 Typical consent to photography in a practice

- ***Illustrative Case #2***: A large tertiary care institution in the Midwest released a videotape of a patient discussing her medical condition and the expert care she received for use in a news broadcast in her home town. The patient filed suit for damages, claiming an invasion of privacy, but she had already signed a release with the provider giving her permission for the images to be used in this manner.
- ***Discussion***: The court dismissed the patient's claim and barred her from seeking damages from the provider, for she had already consented to the exact use that the clinic made in the press release [17]. Consent, where informed, and lawfully obtained, can be an absolute defense to a claim of invasion of privacy. HIPAA/HITECH does not require authorization for photos used in treatment and health-care operations; however, it is common to administer consent for photography, as it pertains to treatment, during intake to a care facility (typically as part of the HIPAA-mandated Notice of Information Practices—see Fig. 35.1) [18]. This is because covered entities certainly "may" obtain consent, even where it is not requisite (for purposes of treatment, payment, or health-care operations). In fact, the Joint Commission recommends obtaining consent whenever patients are imaged for any reason by any health-care entity or provider.

Importantly, general consent, such as that in Fig. 35.1, is not adequate for images to be used in teaching or promotional materials [19]. Some institutions have developed multipurpose consents (covering use of images/photographs for treatment, education, and practice promotion) [20], but for such a device to be valid, it is critical that the patient truly understand what it being proposed, and that he/she makes an informed decision with regard to ***all*** proposed uses. Additionally, it must be made clear that patient care will not be affected by any declination of use in education or practice promotion, lest the release be considered an "adhesion contract," lacking of free will.

Additionally, all clinicians must be aware that images/photos used in treatment and medical decision-making become a part of a patient's medical record [11] and are subject to other aspects of HIPAA/HITECH, as well. Also, as part of the legal medical record, such photos are subject to other federal, state, and local laws regarding record retention, particularly as it pertains to a request for medical records. Consent is not needed for photos/images used to document abusive situations, but these images must be turned over to the proper authorities in a timely manner.

A clinician may use photos containing PHI for educational purposes, to teach students, residents, and other faculty ***within*** an institution, but the images should be de-identified to the greatest extent possible, in keeping with "minimal disclosure" practices. Photos containing PHI may not be used in external setting, such as conferences and seminars, without specific authorization for such use by the patient. Also, a clinician may not take photos containing PHI with them if they depart the original institution, where the photos were obtained, unless authorization to do so was obtained from the patient. HIPAA/HITECH protections regarding PHI may be exercised by the representative of a decedent for 50 years following the date of death.

- ***Illustrative Example #3***: A clinic has a standard photograph consent for treatment (see Fig. 35.1), as part of a Notice of Information Practices. Photographs of a patient's face are taken to document his condition prior to laser facial rejuvenation. The clinician obtains separate signed consent forms to authorize us of identifiable images at regional and national dermatology meetings. The clinician also obtains a separate consent authorizing use on a practice website to promote facial rejuvenation, without remuneration. These uses are explained in plain language. All questions regarding use are answered. The clinician explains the patient may revoke the authorization at any future time. The patient knowingly agrees to all these uses and signs separate releases for educational use and practice promotion. He receives copies of the forms and contact information for the clinic. A laser conference approaches, and the clinician decides to use the patient's identifiable images in a talk she is preparing, but will HIPAA/HITECH concerns impact her legitimate use of the photos?

- ***Discussion***: No, the dermatologist has a signed release that authorizes use of identifiable medical images in just the setting that is planned. While she has included similar (or even the same) images in the medical record, to document treatment, and she will need to conform to all retention policies of HIPAA/HITECH, this does not impair her use in the other ways permitted. Of course, the patient can revoke use, but this has not transpired. Also, conference organizers may require a copy of the signed release, or they may require a statement of indemnification from the doctor that such authorization exists.

Lastly, it is foreseeable that other consent issues may arise simply because of the surroundings of the health-care environment. Of course, patients are allowed to take photos of themselves (so-called selfies), but pictures taken by a patient that include identifying aspects of ***other*** patients in the health-care environment or health-care employees would require consent of those so imaged. Employees of a covered entity must also take "reasonable steps," to prevent unauthorized imaging of patients or other employees without consent. It is not uncommon for employees in a health-care facility to text or email patient information to attending physicians, and it is imperative that emerging technology that is not HIPAA-compliant be avoided to prevent violations.

- ***Illustrative Example #4***: A patient is in a care suite, awaiting a dermatologist who will perform a filler procedure. A "friend" of the patient, in the room with patient permission, takes a picture and posts it to social media, with the title of, "My friend, Jane Smith, BEFORE she gets filler—please take the wrinkles away! (emoticon)." Who is responsible for this potential violation of privacy?
- ***Discussion***: The "friend" is not a covered entity under HIPAA/HITECH, but the clinic can deflect potential liability in a claim of invasion of privacy by posting signage that states, "Unauthorized photography is not permitted in the clinic." Of course there may be suspicion that such a posting is designed to protect the clinic providers from claims of malpractice, but private facilities are able to establish rules of behavior upon private property. Employees can be asked to politely restate the policy, should they become aware of unauthorized imaging. Patients can be asked to take any desired "before" images, beyond those taken by clinic staff with patient authorization, and as part of the care procedure, prior to arrival.

35.6 Basics of Security and Storage of Photographic Images

This is not meant to be a technical treatise, and specifically, no recommendations regarding technology or software packages will be made in this work. In fact, this is true of HIPAA/HITECH itself—in that neither offers, nor mandates, specific technological solutions for physicians then to implement [21]. That said, there are some general principles regarding the capture and storage of patient images that must be followed to ensure compliance with HIPAA/HITECH and to lessen the ramifications and consequences should a security breach transpire.

The same security measures that correspond to other aspects of PHI also apply to the capture and storage of identifiable photographs. While the "written" medical record (either literally handwritten or electronic in form) and any applicable clinical photographs can be physically separate, because of HIPAA/HITECH, and a desire for "portability" of medical information, these elements must be declared to be part of the same "designated record set" (DRS). Moreover, an institution must have a written policy that defines the DRS for patients, including the whereabouts of photos and how these photos will be retrieved, if requested, by subpoena or simply because the patient desires a copy. Under HITECH in particular, clinicians must be able to provide the medical record, including any relevant photographs, to a patient within 48 hours, and this must be kept in mind when designing the DRS [11].

Encryption is code-based technology that is used to transform data to render it unreadable and incomprehensible to unauthorized users who lack the decryption technology to transform the "scrambled" data back into a usable form. HIPAA/HITECH defines encryption as follows: "the use of an algorithmic process to transform data into a form in which there is a low probability of assigning meaning without use of a confidential process or key" [22].

While strictly speaking HIPAA/HITECH does not mandate use of encryption, it does state: "[a] covered entity must… [i]mplement a mechanism to encrypt and decrypt electronic protected health information" [23], or the covered entity must implement an equivalent solution to meet this requirement. Precisely what this "equivalent system" would entail is unclear. Hence, encryption of PHI, both "at rest" (stored in a database) and "in motion" (transmission to or from a database, or to and from a covered entity or business associate), is a de facto requirement. When electronic images are used in dermatology, both the storage system and any electronic pathways into or out of the database must be encrypted using HIPAA-compliant technology. A recent HIPAA settlement, where a laptop computer containing the PHI of approximately 13,000 patients and research participants, was stolen from the car of an employee of the health-care provider resulted in a $3.9 million payment to the HHS [24]. The investigation revealed the health-care facility's "security management process was limited in scope, incomplete, and insufficient to address potential risks and vulnerabilities to the confidentiality, integrity, and availability of ePHI held by the entity" [24].

At present, HIPAA/HITECH stratifies security breaches into those that affect fewer than 500 patients and those that involve 500 or more patients. Breaches that involve 500 or more patients must be reported to HHS within 60 days of discovery, while breaches involving less than 500 patients may be reported annually. Covered entities must notify affected individuals in written form, by first-class mail, or alternatively, by e-mail, if the affected individuals have agreed to electronically receive such notices. If there are 10 or more persons affected with insufficient or out-of-date contact information, the covered entity must substitute individual notice by posting the notice on the home page of its website for at least 90 days, or by providing notice in major print or broadcast media where the affected individuals likely reside.

The covered entity must also include a toll-free phone number, which remains active for at least 90 days, where individuals can learn if their information was involved in the breach. If the covered entity has insufficient or out-of-date contact information for fewer than ten persons, the covered entity may substitute telephone contact for written notice. Covered entities with breaches involving 500 or more persons are posted on the HHS website (see: https://ocrportal.hhs.gov/ocr/breach/breach_report.jsf).

Clearly all of this notification comes at considerable cost to institutions, and therefore, it may be surprising to learn that use of encryption, where there is substantial likelihood that the lost data does not exist in any usable form, obviates the need to report a breach. In fact, on the HHS website, there is the following guidance:

> Covered entities and business associates must only provide the required notifications if the breach involved ***unsecured*** [emphasis added] protected health information. Unsecured protected health

> information is protected health information that has not been rendered unusable, unreadable, or indecipherable to unauthorized persons through the use of a technology or methodology specified by the Secretary in guidance [i.e. “encrypted”].

Therefore, encrypting institutional PHI, as well as ensuring that all business associates, such as database “cloud” purveyors, have HIPAA-compliant practices and encryption, will be financially more advantageous than dealing with a breach, not to mention suffering the reputational damage that ensues with regard to patient confidence.

- ***Illustrative Example #5***: A dermatology practice keeps “before and after” images of micrographically controlled surgeries from approximately 2200 patients on an unencrypted USB drive. The USB drive was stolen from an employee’s vehicle and was never located. What are the relevant details of the breach?
- ***Discussion***: In this case, the breach involved more than 500 persons, and the lost device was unencrypted. The practice had to report the breach to HHS within 60 days of discovery. In this case, the dermatology practice had to pay a fine of $150,000.00, and the settlement included also a corrective action plan to address and mitigate security risks and vulnerabilities [25].

This case also highlights why it is undesirable to leave images upon unencrypted electronic devices. Most digital cameras do not encrypt data, and the images should be transferred quickly to a larger encrypted database. It is unwise to accumulate days or weeks of patient data upon a camera, for fear it will be lost, and a large-scale breach will transpire. Wireless fidelity (WiFi) cards that immediately transmit the image data to a secured database, and then wipe clean after transmittal, avoid this problem of data unencrypted “at rest.” In 2013, a dermatology practice settled with HHS for $1,215,780 for selling a photocopier to a third party which potentially contained the PHI of 344,579 individuals [26]. This illustrated the importance of cleaning devices of patient’s records before selling or otherwise transferring such device.

35.7 Closer Examination of the HIPAA Security Rule

This paper concludes with a more detailed analysis of the so-called security rule of HIPAA/HITECH. For the proper security of PHI, HIPAA/HITECH requires three elements to be present in an overall security plan, namely:

1. Administrative security measures
2. Physical security measures
3. Technical security measures

Each of these elements will be expanded upon to afford greater insight into a HIPAA-compliant security plan for PHI, to include identifiable patient images.

Administrative safeguards provide management, accountability, and oversight structures for covered entities, to ensure that proper safeguards, policies, and procedures are in place with regard to PHI. Most often, this consists of designated administrative personnel who conduct periodic risk assessments, who establish employee training procedures and who ensure that the proper infrastructure exists to keep PHI from being lost or destroyed.

Physical safeguards establish actual physical barriers to prevent unauthorized physical access to PHI. Most often this consists of keeping close inventory of imaging or database-access devices, storing such devices securely, and when such devices cannot be located, taking measures to shut down and wipe clean lost devices.

Lastly, technical safeguards consist of automated processes used to protect data and control access. Most often this consists of antivirus and anti-malware software, firewalls on computer system, encryption of PHI, biometric recognition procedures to control access to database, and other related measures.

Ultimately, each of these elements (administrative security measures, physical security measures, and technical security measures) must be woven into a singular HIPAA/HITECH-compliant imaging plan for dealing with identifiable patient photographs inside a dermatology practice. The very nature of dermatology, being a visual specialty, makes it unlikely that without a formal plan, a truly secured and compliant photography plan can be achieved without foresight and appropriate planning.

35.8 Conclusion

In summary, identifiable images, whether of the patient's full face or simply identifiable for other reasons (unique tattoos or birthmarks), represent information that must be afforded an appropriate degree of privacy. This is not only the ethical thing to do for patients, but also HIPAA/HITECH consider these identifiable images to be, formally, PHI that is afforded the same protections as names, initial, dates of birth, or other personal data. As such, failure to afford digital images appropriate privacy protection will result in substantial monetary and nonmonetary HHS penalties.

Not only must photos taken in the course of treatment be considered a part of the patient's medical health record, but also appropriate consent and authorization must be obtained prior to use of images in extramural educational endeavors and in practice promotion. Failure to obtain appropriate consent and authorization is not only an ethical lapse, but it may expose one to legal claims regarding invasion of privacy.

The privacy and security provisions of HIPAA/HITECH mandate that PHI, to include identifiable patient images, be encrypted, both "in motion" (when transmitted) and "at rest," to ensure that any unauthorized disclosure, to include data theft, is unlikely to result in any use to the detriment of patient privacy. Should unencrypted data be lost or stolen, specific requirements exist regarding notification of patients affected by the breach. When unencrypted data is compromised, it is imperative that the proper notice requirements are followed or else significant liability may attach. Appropriate HIPAA/HITECH-compliant patient imaging plans, when administered by covered entities and consisting of appropriate physical and technical safeguards, serve to ensure that patient data remains safe and that patient privacy is honored.

Acknowledgment *Disclaimer*: This article is NOT legal advice. It represents a review of some relevant medicolegal issues from the perspective of the authors. Should you have a specific legal situation, involving privacy and/or imaging concerns, you are advised to contact a licensed attorney in your state to discuss the situation.

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Cyber Security: Medical Photography and Social Media

36

Christopher G. Seidel

Contents

36.1 Introduction

There is no doubt that the proliferation of digital cameras and prevalence of high-speed internet have tremendous positive effects on the field of medicine and overall patient care. The ability to take a digital photograph (or X-ray, MRI, CT, etc.) in one location and transmit it electronically to the other side of the world to be read and diagnosed within moments is indeed a marvel of modern technology. It is a marvel for which this author personally gained an appreciation when an X-ray was taken at a small remote clinic with limited staff but transmitted instantly to a radiologist at a large urban medical center for reading and diagnosis. As with all fields, the efficient sharing of healthcare images and information typically leads to increased knowledge and a reduction in time (and often cost) to accomplish a given task. The use of medical photography and digital transmission of images is no exception. This book is dedicated to that very topic. This chapter, however, is dedicated to the risks inherent in that use of technology.

Each advancement in the technology used to capture, store, and transmit digital information, such as photographs, has also brought increased vulnerability of that information to be intercepted, compromised, or withheld. More simply put, increased sharing of information also means

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the possibility of that information being accessed by those who should not.

In this chapter we will review some of the fundamentals of cyber security and cyber crime, some of the threats specific to healthcare data and images, and ways to mitigate those threats.

36.2 Overview of Cyber Security

36.2.1 Cyber Security

For a term that did not exist a few decades ago, it has certainly received a lot of attention in recent years. What is it? Why should we care?

The widely accepted definition of cyber security is "measures taken to protect a computer or computer system (as on the Internet) against unauthorized access or attack" [1]. This is a definition that this author has never liked. I reject this definition because it fails to identify the most important part of cyber security: the information. Protecting the data is the primary concern. Organizations today care much less about the computer hardware than they do about the data stored on that hardware. Relative to proprietary or personal data, computer hardware is cheap. Consider the analogy of a safe. Do you care more about the metal box or the valuables stored within it? If your personal computer was stolen would you rather receive back your empty computer or all your personal data and pictures? For the purposes of this chapter, we will define cyber security instead as "measures taken to protect digital information from unauthorized access or attack."

Unfortunately most people today fall into one of two extremes when considering cyber security. They either don't think about it much at all, or they tend to be obsessive about it. Far too many people fall into the former group and not enough in the latter. The truth is, a healthy attitude toward protecting your personal or organizational data should fall somewhere in between these two groups. Gone are the days when anyone can say they are not concerned with this topic because they do not use a computer, or manage their finances online. You are online whether you like it or not. Employers, banks, local and national governments, and healthcare providers all keep your data stored digitally online. While the obligation to safeguard this data certainly falls with the keeper of the data, we as owners of that information have the burden of holding those organizations accountable as well as doing what we can to protect our data. What can we do to protect that critical information? The first step is to remember one fundamental concept: every time a single information system (computer or device) or group of systems (network, Internet, etc.) is storing, transmitting, or receiving important data of any kind, cyber security MUST be a concern.

Those in a position to deploy information systems or networks of systems (a relatively small group of technical people) must consider the security of the data—first, last, and often. Those in a position to access or use those systems (everyone) must use some simple best practices to ensure the cyber security measures in place on the system have every chance to be effective. Those designing systems tend to focus on the functionality and cost of the system with security as an afterthought. Those purchasing these systems (including smart phones/devices and personal home computers) tend to focus on the ease of use and the cost as well. This is entirely understandable. "I want the smart phone that best meets my needs at the lowest cost." This sounds reasonable to anyone. However, cyber security must be a primary concern for systems designers and integrators and should be at least a secondary concern for purchasers. Getting to this point will be a fundamental paradigm shift in all industries and consumer markets. Making this transition will be the best way to stay ahead of cyber threats.

36.3 Cyber Concepts

As already mentioned, cyber security is all about protecting the data. The idea of protecting data can be vague until you break it down. Whether that data is digital images of a patient's skin ailment or bank account numbers, the fundamental concepts of safeguarding it are the same. What matters is that the information maintains confidentiality, integrity, and availability. This is a

Table 36.1 The CIA Triad as it applies to healthcare data and images

Concept	Application	Healthcare example
Confidentiality	A patient's data must remain private. It should be accessible only to the patient (or designee) and the minimum number of healthcare providers required to deliver quality care.	There have been many breaches to the confidentiality of healthcare data, including images. This data is very lucrative when sold or used to commit fraud.
Integrity	A patient's data must be reliably accurate each and every time it is accessed.	If the data specific to a patient's diagnosis, prognosis, or history of medical care is altered or confused with that of another patient, it could be life-threatening.
Availability	A patient's data must be consistently and readily available to those that need access.	A growing concern in healthcare is what is known as a ransomware attack where access to data is denied until the victims pay to retrieve their data.

concept known in cyber and information technology (IT) circles as the CIA Triad. The CIA Triad and how it applies to patient healthcare data such as digital imagery is outlined in Table 36.1.

An information system that adequately addresses each of these concepts can be considered secure. Too many systems only address one or two of these concepts, or if addressing all three do not go into enough depth to provide adequate measures of security. For example, using a public social media site to share medical photographic images might ensure that the images are available for the patient; however it does little to ensure confidentiality. Even sending the image from one smart device to another does not ensure confidentiality as a telephone provider would have access to the image. The obvious question is what type of system would adequately address each of the critical components? Unfortunately, the answer becomes increasingly complicated as the technology advances.

In many ways, complexity is the enemy of security. With every new advancement in the technology to capture, store, and transmit data comes one, or several, new vulnerabilities. For many years after the advent of computers, records were still relatively secure from unauthorized access or attack. These were stand-alone computing systems without the ability to digitally send data to other systems. Your doctor may have had a computer, but without the Internet or even a local area network attached to the computer, the only way at gain access was in person. The advent of wide area networks, the public Internet, and, subsequently, systems like healthcare portals has greatly increased the sharing of information between doctor and patient. It has also increased the number of vectors for unauthorized access or attack. This does not mean healthcare providers should return to the days of paper records. As with almost every industry today, the introduction and proliferation of digital information sharing has yielded tremendously positive effects in the healthcare industry. There is little doubt the ability to share patient records and imagery between care providers, consultants, and patients can improve the quality and timeliness of care. Providers and patients share the responsibility of ensuring that this data is captured, stored, and transmitted securely. Without doing so the benefits may be outweighed by the costs. Electronic Protected Health Information (ePHI) should only be stored and shared via systems that were securely designed to do so.

While they do provide some level of encryption and authorization for users, social media websites and applications are not designed to adequately protect private patient data. Almost all social media platforms would violate the first concept of the CIA Triad—confidentiality. The overly lengthy End-User License Agreements (*that most users accept without reading*) clearly state the vendor will have access to photos, posts, etc. Systems designed to share patient data should be "closed-loop systems." This means everyone who has access to a patient's images or data should be authorized to do so. Users of the system must be required to log in to the system at both ends with discrete, secure credentials. Data must be encrypted. We will take a closer look at encryption and authorization later. Even on a properly secured closed-loop system, users today are accessing the data with varying kinds of devices. The expansion of the Internet of Things has made securing data more complex.

The Internet of Things (IoT) is a phrase used to describe our global digital network in the modern world. This network is no longer comprised of just computers, servers, and printers. In most offices and homes, this network now includes telephones, tablets, televisions, gaming systems, appliances, thermostats, and an ever-increasing number of other devices. While most of these devices may have nothing to do with the storage or transmission of medical imagery, when installed on the same network with devices that do, they must be appropriately segregated and/or secured. One of the largest cyber breaches in the United States history took place in 2013 when the Internet-connected heating and cooling system of a major retailer was exploited by hackers to gain access to 40 million customer financial records. There is nothing inherently wrong with connecting the heating and cooling systems to the Internet. This gave the corporation greater control of the systems and improved insight into the related costs of running those systems. However, just as with storing and transmitting medical images, the benefit must outweigh the potential costs. By not adequately securing the online heating and cooling system and not properly segregating that system from the financial records of customers, the costs became much greater than the benefit. In this instance, the confidentiality, integrity, and availability of the customer's records were all compromised. This was not a failure of the technology. As with most cases of cyber breach—this was human error.

In cyber security there is a concept of the 80/20 principle. This is not to be confused with the more established Pareto Principle which states that 20% of the inputs generate 80% of the outputs. The cyber 80/20 principle is a concept that only 20% of cyber breaches are caused by true failure of the hardware or software used to store the data. The other 80% are caused by human behavioral errors. In the example above a person failed to properly secure the corporate network of the retailer. The heating and cooling company that installed the system failed to safeguard the credentials to access the system. If properly designed, implemented, and safeguarded, there is no reason not to believe that this breach would have been prevented. This is not to say that hardware and software do not have flaws. When these are identified by either the manufacturer or the users, they are typically known as zero-day vulnerabilities. These are vulnerabilities to the hardware or software that do not yet have a patch or mitigation. When these are exploited, it should typically be considered a failure of the hardware or software. More often than not (approximately 80% of the time), a patch or mitigation has been developed by the manufacturer or user community but not been implemented by the owners of the breached system. Aside from properly configuring and patching all systems, there are many things that system owners and end users should do to ensure patient data is secure.

36.4 Cyber Best Practices

The most fundamental aspect of cyber security for both healthcare providers and patient/end users is *safeguarding physical access* to information systems. Physical access refers to the ability to actually stand at an information system and touch it. For the provider this means that the hardware used to capture, store, and transmit images and other data has limited access. For example, not every employee or visitor to a hospital or care facility needs or should have access to the information system. Systems for capturing images must be controlled devices. These devices should be inventoried and tracked. Caregivers should never be using personal devices for capturing or recording patient images or data. The purpose of using only inventoried, tracked devices is to ensure the level of security on these devices is at or above certain standards. These capture devices (scanners, cameras, etc.) should be physically secured when not in use. The systems that store the data (computers, servers, databases, etc.) should likewise be physically secured. For the patient and other end users, safeguarding physical access is akin to not leaving your laptop of smartphone unattended in a coffee shop. Likewise it is not recommended to check your personal health data at public use computers such as Internet cafes and public libraries. These are basic concepts that are obvious steps to safeguarding ePHI or other important data. These concepts can go a long way to enhancing the confidentiality, integrity, and availability of data within a system.

Second only to the most basic level of safeguarding physical access is *safeguarding logical access*. Logical access refers to the ability to "log into" a system either remotely or in person. For the provider, this means enforcing strict policies surrounding which employees have credentials to access patient data. These policies at a minimum must include unique usernames or identifications for every user, unique strong passwords, forcing periodic changes to these passwords, and disabling or removing dormant accounts. For the patient and other end users, safeguarding logical access is largely the same concept. Most users of smartphones and other mobile devices do use a Personal Identification Number (PIN) or password to secure their device. How often do they change it? Do they share that PIN or password with others? How about devices in the home? Are they also secured with a unique strong password? Many computing devices today offer the ability to save a fingerprint to use as a method to safeguard logical access. This is a form of *Multi-Factor Authentication* (MFA). MFA offers additional protections to logical access by requiring a second (or more) form of authenticating your identity to the system before gaining access. This is the same concept as providing multiple forms of identification to a vendor before making a large purchase. For years, many Internet-based email, storage, and financial products have offered end users the ability to enable MFA. Following this cyber best practice, many patient information portals now offer the end users MFA as well. The typical scenario is that after providing a unique username and password, the system might send an additional PIN as a text message to a previously registered mobile phone. This PIN must also be entered prior to gaining access the information system containing ePHI. Sometimes this level of MFA is used only for the first time using a new computer or device, and sometimes it is used at every system logon. The former should be enabled at a minimum and ideally the latter. End-user patients using systems that do not require all of these cyber best practices (unique usernames, strong passwords, and the opportunity to leverage MFA) should know that their personal data is not as secure as it could be and should demand more from their healthcare providers.

Once physical and logical access has been adequately protected, there are additional steps that we, as purveyors of cyber security best practices, must implement. One of the most important steps is *data encryption*. Data encryption refers to the practice of converting the data into an unrecognizable format or code in such a way that only those authorized to "decode" and view the data can do so. While there are many good books written on the topic of encryption, we will only review the very basics in this chapter. At a foundational level, the process of encryption means taking data that's in its natural state and encoding it so that is no longer readable without first decrypting it. This natural state is often referred to as plain text—text that is plainly decipherable and legible. This also applies to photographs and other images that can be read and interpreted. The process of encryption typically involves the use of keys. A key is generated to be able to encrypt the data into a format that is no longer plainly readable or interpretable. A corresponding key is then required to decrypt the data back to a readable format. As one might expect, data encryption comes in varying strengths. Some methods and levels of encryption are much more secure or "stronger" than others. With the software available today, this process of encrypting and decrypting data is not nearly as scary or cumbersome as it seems.

Most social media applications and systems offer at least some basic level of encryption today. However, like the use of MFA discussed above, often encryption must be enabled for use by the end user. For example, the typical personal computer or smartphone purchased today is capable of encrypting the data stored within it… if the user chooses to do so. Users of social media, text messaging, and other forms of communication often declare the applications they use to communicate are encrypted, and as a result their data is secure. This is only partially true.

Let's imagine a scenario where a healthcare provider has a laptop computer that contains ePHI for her patients. She and her organization have ensured that the cyber best practices for safeguarding physical and logical access have been followed. When using the laptop, the provider only transmits personal patient data such as records and images through the approved system. What if she uses a public internet connection at a coffee shop to transmit the data? What if the laptop is stolen? In this scenario the methods already discussed for safeguarding physical and logical access may or may not be enough to keep the data secure. If the password or PIN is compromised or otherwise circumvented, the data stored within the device could be available for anyone to see. If the Internet connection used to access the approved patient portal is unsecure, the data being transmitted could be available for anyone to view, steal, or even modify. From this scenario one can see that there is more than one place the healthcare provider needs to ensure the security of that data: as it sits on her laptop and as it is being transmitted to another system.

Data in an information system exists in two basic states: *data at rest* and *data in motion*. These two states are largely self-explanatory. Data at rest is the data that resides within an information system not being transmitted to any other system. Data in motion is the (possibly the same) data as it is being transmitted between information systems. The diagram below depicts a very basic overview of when data is at rest and when it is in motion (Fig. 36.1).

Each of these states of data presents unique challenges and benefits for securing it via encryption. For data at rest, the media on which it is stored can be encrypted either in its entirety or just the portion holding certain data. Gaining access to this encrypted media would only provide encoded data that is of no value unless the proper keys are used to decode the data. Data that is being digitally transmitted (either through wires or wirelessly) obviously does not have storage media that can be encrypted. As data is transmitted, it is broken down into small packets, delivered, and reassembled back into the original file or picture. Without physical media to secure, it is these packets that must be encoded via encryption. There has been much debate recently about the level of encryption provided for data in motion on social media sites and applications as well mobile devices. It is very typical for a social media site to encrypt the user's data to protect it from other end users, but that data is still exposed to the vendor providing the site. While this scenario may be acceptable for pictures of family vacations or pets, it is not up to the standard of privacy required for ePHI such as medical photography. Medical photographic images must be encrypted while stored to be kept private from both unauthorized end users and platform providers. For example, the photographs used to help diagnose and monitor a patient's skin ailment should be accessible to patient and care providers but not the technology company that created or even hosts the patient care portal. The host of such a portal should provide full encryption of these photographs, while they are stored, as well as being transmitted in, out, or around the system. Data encryption is not perfect, but when properly implemented it provides the best means of ensuring that important data retains its confidentiality and integrity. Encryption can be broken with enough time and expertise, but methods of encrypting data more securely are being developed and put into practice every day.

Each of the cyber best practices discussed in this section relies on proper implementation to be effective. As is proven time and again in the 80/20 principle, it is most often human error that causes private data to be accessed by unauthorized users. Neglecting to use and safeguard a unique username and/or strong password is responsible for the vast majority of cyber breaches. While most of us may not be in the

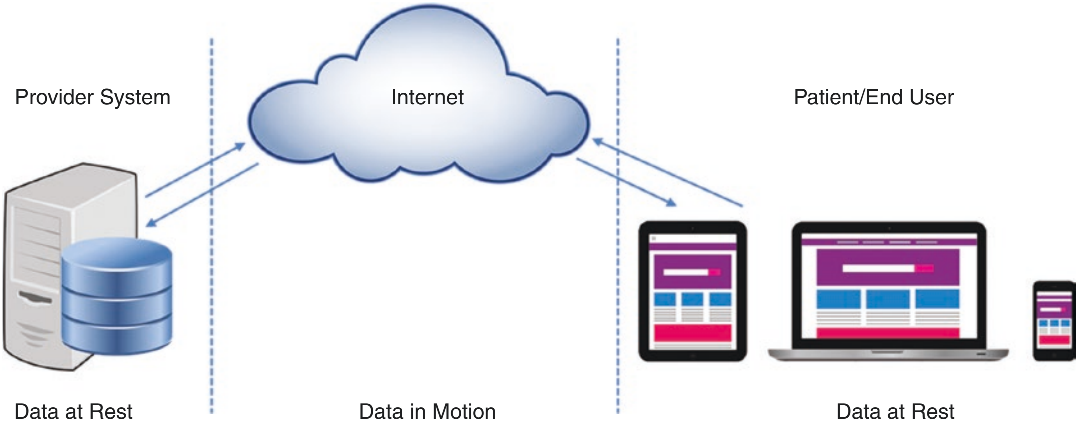

Fig. 36.1 A simple depiction of when data is at rest and in motion

position of designing or implementing a complex information system to store or transmit patient images and records, we are all end users who need to remain vigilant with some basic habits and behaviors to keep personal data safe.

36.5 Practice Good Cyber Hygiene

It is the nineteenth-century Hungarian physician Ignaz Semmelweis who is most often credited with the adoption of proper hygiene practices in medicine. Without knowing exactly why, Semmelweis discovered that doctors washing their hands reduced the mortality rate among mothers who had just given birth. It would be a few more years until Pasteur confirmed the theory of germs and their role in infection and disease. While the benefits of sterile healthcare facilities are common knowledge today, Semmelweis' discovery was met with rebuke and harsh criticism. It seems doctors were insulted at the thought that it was their unclean hands that led to the demise of their patients. The same can be said today regarding proper cyber hygiene. Nobody wants to believe that it was their bad habit or neglectful behavior that led to the compromise of personal data. More often than not, that is precisely the case.

Just as the practices and habits of proper hygiene are taught to children to reduce illness and infection, we all must learn some basic practices and habits of proper cyber hygiene. Much like washing hands, most good cyber hygiene habits are fairly simple. The table below depicts the most common habits of good cyber hygiene that all users should remember and why.

All of the good cyber hygiene habits in Table 36.2 can be implemented with minimal effort and at little or no cost. When practiced together consistently, they offer users a much greater chance of adequately securing their data. They key here is to practice them consistently. Of course there are additional layers of enhancing your cyber hygiene that many users choose to implement as well. Making use of a Virtual Private Network (VPN) creates a secure encrypted tunnel from your device to another network. This can keep your personal data secure from those that should not see it. Many users implement extra layers of encryption on top of the basics that may have been provided by the system. Both VPN and encryption packages are available as software suites that can be added to your computer or mobile device to increase your security and peace of mind.

36.6 Cyber Security Concerns in Healthcare

For many years financial records such as credit card information were the number one target for cyber thieves. The reason was clear: obtain the information and sell it to criminals for a high profit. In recent years the healthcare indus-

Table 36.2 Good cyber hygiene habits that should be practiced by all users

Habit	Example	Benefit
Always use a strong password	While using something like your child's name or birthday is easy to remember, it is also easy to guess.	A strong password enhances the safeguarding of confidentiality, integrity, and availability of data.
Use unique password for different systems	Resist the temptation to find one strong password and use it for all systems you access. If it is compromised on one system, it is then compromised everywhere.	A unique password also enhances the safeguarding of confidentiality, integrity, and availability of data by preventing a single system compromise from becoming widespread.
Enable system locks after dormancy	Most laptops and mobiles devices have settings to lock themselves after a defined period of no use.	A strong password is of no benefit if it is not in place when your device is stolen.
Do not share usernames and passwords to private systems	As costs to access social media and entertainment sites and applications continue to rise, there is a temptation to share credentials with friends and family. This should not happen with private systems such as finance or healthcare.	This is not a question of trusting that family member or friend to not reveal your credentials. If their computer or mobile device is compromised, your data is now potentially exposed as well.
Avoid public Wi-Fi connections for certain activities	The shared Wi-Fi at the café might be suitable for a quick Internet search or social media but never for private systems such as finance or healthcare.	An unsecured (or secured with a widely shared password) Wi-Fi potentially exposes your data, as well as your user credentials, to anyone and everyone on that network.
Keep computing hardware and software updated	The manufacturers of all reputable hardware and software provide regular updates to enhance the functionality and security of their products. The only way to remain secure is to stay current with these updates.	New exploits for hardware and software are found every day. A system that was previously considered secure may no longer be when left out of date. There are many vectors of cyber attack that may be prevented by a simple, quick update.
Use security software such as antivirus and firewall suites	Every computer or mobile device has many reputable options for security software specific to that operating system that can be added to greatly enhance your security. Resist the temptation to save on cost or convenience.	While some security features are built into operating systems today, there are always additional layers or third party packages that can be added to increase the overall security posture of your devices.
Only use reputable software	Only software from reputable vendors should ever be downloaded onto your computer and mobile devices. Many applications such as enticing children's video games are full of malware [2] that will compromise your system.	Downloading software from an untrustworthy vendor can compromise your security because it bypasses your fundamental defenses such as username, password, firewall, etc.—just like inviting a burglar into your home.

try has become the number one target for cyber crimes. In fact, healthcare cyber attacks in the United States have increased to the point where this industry comes under attack twice as often as other industries [3]. The reasons for this may not be as obvious as the credit card example. It turns out healthcare records (including images) are even more profitable to cyber criminals than financial data. According to a recent white paper authored by FireEye, a leading cyber security company in the United States, healthcare records are incredibly lucrative. Whereas a single credit card number will only bring between $1 and $20 today on the black market, a single medical record can be expected to fetch upward of $50. An entire package of healthcare data, including imagery, for a single patient can be sold for $500–1300! [4] These records are sold to facilitate identity theft and healthcare fraud.

The 2017 WannaCry ransomware attack rapidly became one of the most prolific cyber attacks in history. It spread to more than 300,000 information systems in over 150 countries in just a few days. The victims included consumer, commercial, government, and healthcare sectors. The losses have been estimated to be in the billions (USD).

The most prevalent type of cyber attack on the healthcare industry in recent years has been ransomware attacks. Just as the name suggests, this is a type of malware that holds the victims data “hostage” for ransom. In this attack, the attackers focus on the availability of the data. They capture the data, while it is in motion or at rest, and render it inaccessible. This is accomplished by actually stealing the data or even just encrypting it with their own complex code. The victim is provided instructions on how to pay the ransom for the safe return of their data. With no other alternative at their disposal, many hospitals and healthcare providers in recent years have paid the ransom to retrieve their patients’ data. The only way to prevent a ransomware attack is to ensure that physical and logical access to the data is secured. Encrypting the data and having recent backups of all critical data will lessen the impact of a ransomware attack. Ransomware attacks are certainly not unique to the healthcare industry, but given the critical nature of medical records and images, they have become the most prevalent form of attack in this industry. In 2017, the so called “WannaCry” cyber attack became one of the most prevalent in world history. This was a ransomware attack, and it had devastating effects on the healthcare industry.

Ransomware attacks often come as a result of an advanced persistent threat (APT). APT is a lengthy prolonged cyber attack in which the intruders gain access and remain undetected for an extended period of time. The purpose of this is usually to monitor network activity and to gain a better understanding of what data is available to compromise. The goal of APT is not usually corruption or destruction of the information system. APT is typically an enduring, long-term attack aimed at stealing the maximum amount of data before being detected and mitigated. These attacks are complex and often require a tremendous amount of effort. As such, attackers will be seeking a large payoff. APT is often accomplished by exploiting zero-day vulnerabilities and/or leveraging social engineering. Zero-day vulnerabilities were explained earlier. Attackers can use them because the manufacturer is either unaware of the weakness in the system or has yet to mitigate it. Social engineering is most often carried out with phishing emails. These are email messages that convince the recipient that they should provide their user credentials. Once the attacker has these credentials, they have unfettered access to the system. Victims of phishing attacks typically do not know they have provided their user credentials to a fraudulent user until it is much too late. It typically takes an organization months, if not years, to discover they have been breached by APT. In a 2017 report, analytics company Protenus found that the average amount of time to discover a breach in the healthcare industry was 308 days [5]. The report also confirmed insider wrong doing as the leading cause of breaches in healthcare. Sometimes the insider has malicious intent. More often, like the unsuspecting phishing attack victim, they merely had poor judgment or lack of proper training.

36.7 Cyber Security Concerns Specific to Medical Images

Digital images also have inherent cyber risks that other data formats often do not. Many users are unaware that a typical image, especially those taken with standard commercial devices such as digital cameras and smart phones, embed a tremendous amount of data within the picture file. This data is known as metadata. Metadata provides information about other data—in this case the image. The metadata is captured at the time the photograph is taken and is embedded in the image file. Metadata can include very specific information such as the owner of the camera, the manufacturer and model of the camera, the time and date of the picture, and even the Global Positioning System (GPS) coordinates where the photograph was taken! It is easy to understand how this could pose a serious privacy risk to a patient. Withholding the patient's name for privacy on a medical image will have little benefit if the metadata of the photograph contains the precise GPS coordinates of their home.

Typical consumer products such as smartphones, tablets, and other devices with cameras typically capture and embed all of this metadata by default. That is to say, it must be manually turned off before taking photographs. Compounding this problem, many social media applications and sites keep this metadata attached when the photographs are posted online. As mentioned earlier, a smartphone is a wonderfully helpful tool, but it should not be used to capture private patient images. At the very least, the healthcare provider or patient photographer should change and/or alter the settings of the device to control the amount of data that is captured and embedded with the photo. This is not to say that metadata should be eliminated from photograph capture. If used properly the information contained in the metadata of a photograph can have tremendous value for tracking and cataloging patient data.

Another cyber challenge not unique to medical imaging devices but often found is outdated software and/or operating systems. Medical imaging devices are tremendously expensive. As such, healthcare providers cannot replace or update as often as they might like. Many of these devices run on outdated, unsupported operating systems. As discussed earlier, all information systems, including imaging hardware, should be kept up to date per the specifications of the original equipment manufacturer. If the system is no longer supported by the manufacturer—but remains in use and connected to the network—it poses a significant cyber threat to the whole enterprise. Many old operating systems and software suites have known exploits that can be used by cyber criminals to gain easy access to data. Reputable manufacturers have very clear guidelines for how long they will support all software and/or hardware they produce with required security patches and updates. These manufacturers typically announce well in advance when a particular piece of hardware of software will reach "end of life." Healthcare providers and patients alike should pay attention to these guidelines and update hardware and software as required.

36.8 Conclusion

At this point you might feel the only way to successfully combat this relentless barrage of cyber attacks is to disconnect devices and stop using digital images in the care of patients. This is not so. As mentioned earlier the benefits of capturing and transmitting digital images in the care of patients can vastly outweigh the risks. When implementing a system to capture, store, and disseminate medical images, the inherent security posture of the system cannot be an afterthought. It is incumbent upon providers to ensure that the security of the data, and as a result the patient's privacy, is paramount. Providers must use basic cyber best practices such as safeguarding physical and logical access to the system. This includes limiting the access to only those who require it and ensuring they are all properly trained on how to safeguard information. Providers must employ industry standard encryption to safeguard the data, while it is at rest within the system and while it is in motion to patients and other healthcare providers. The challenge to protect this data is not only on the providers. We as patients have a tremendous responsibility to do our part to protect our own data. By practicing good cyber hygiene and being careful with how we access or share our data, we can expect to be reasonably safe from cyber attack. Both providers and patients must stop being reactive when it comes to cyber security. Providers cannot wait until after a breach to enhance the security of the systems they deliver. Likewise, patients cannot wait until a notice from the provider that their data may have been compromised to develop good cyber hygiene habits. While information systems and digital imagery is certainly a technical field, one thing remains clear: cyber security is not just a technology problem—it is a human behavior problem as well.

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Imaging Archives for Teaching, Learning, and Research

37

Ofer Reiter and Allan C. Halpern

Contents

37.1 Introduction

For many years, dermatologists and dermatology departments have maintained collections of medical images, in the form of film passed photographs or projection slides, for teaching and research purposes. These physical collections were kept in offices, hospitals, health institutions, libraries, and museums and were primarily accessible for their owners. Since the introduction of digital photography, medical images have become much easier to obtain. This has led to a massive increase in the use of medical images [1] and to the creation of large aggregates of dermatological images. Imaging archives are not unique to dermatology and exist in other medical specialties. These include radiology, with an emphasis on neuroradiology and oncology, ear nose and throat, ophthalmology, dentistry, plastic surgery, gastroenterology, hematology, pathology, and many more.

Aside from traditional clinical monitoring, teaching, and learning, one of the major recent drivers for the creation of large imaging archives is the development of machine learning (ML) algorithms, which are a subset of artificial intelligence. Within the context of medical imaging, ML algorithms are processes in which a software "learns" to identify different features in an image and, eventually, generates a diagnosis based on those features. The algorithm must be trained using many different images for it to be accurate and comprehensive, and this requires imaging archives containing thousands or more images per diagnostic category. In addition, these images must be tagged with a "ground truth" diagnosis

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for the software to be able to connect the different visual features with a correct diagnosis.

This chapter will provide a review of the current state of medical imaging archives, with a special emphasize on dermatology.

37.2 Different Categories of Imaging Archives

There is no exact definition for what is considered an imaging archive, and there is no cutoff for the number of images required to be considered one. As mentioned above, imaging archives can be digital or physical (e.g., paper, film, etc.). A quick Internet search returns thousands of medical images readily available for viewing and download from many websites, each containing anywhere from one to thousands of images in different contexts. Nevertheless, the different imaging databases that are currently available can be generally divided into three major categories: medical atlases, private image databases, and free online databases.

37.2.1 Medical Atlases

This is by far the largest category of archives and it includes both online and printed atlases. The images appear in conjunction with the definition of each entity. Atlases usually include many entities, and their primary goal is to aid in teaching. Out of the online atlases, some are open-access and others require paid subscriptions.

In dermatology, atlases are mostly clinical (as opposed to dermoscopic images) and include also histological images. Examples include www.dermnetnz.org with over 20,000 clinical images, www.derm101.com, home to the Dermquest database with over 22,000 clinical images, and the Atlas of dermatopathology (https://atlases.muni.cz).

Examples from other fields of medicine include the *Atlas of Ophthalmology* (www.atlasophthalmology.net) and a list of multiple atlases in radiology that can be found on www.radiologyeducation.com.

37.2.2 Private Image Archives

Many medical centers, universities, and physicians maintain private image databases of their patients. These databases are used for clinical purposes (such as short-term monitoring) and for teaching and research purposes. They range from a few dozen to hundreds of thousands. The databases are not accessible to the public and are either on the internal servers of the institutions or require permission to access. In dermatology, these databases can include clinical, dermoscopic, and histopathological images. Examples include the University of Edinburgh database (https://licensing.eri.ed.ac.uk/i/software/dermofit-image-library.html) and the Asan Medical Center archive [2].

37.2.3 Free Online Archives

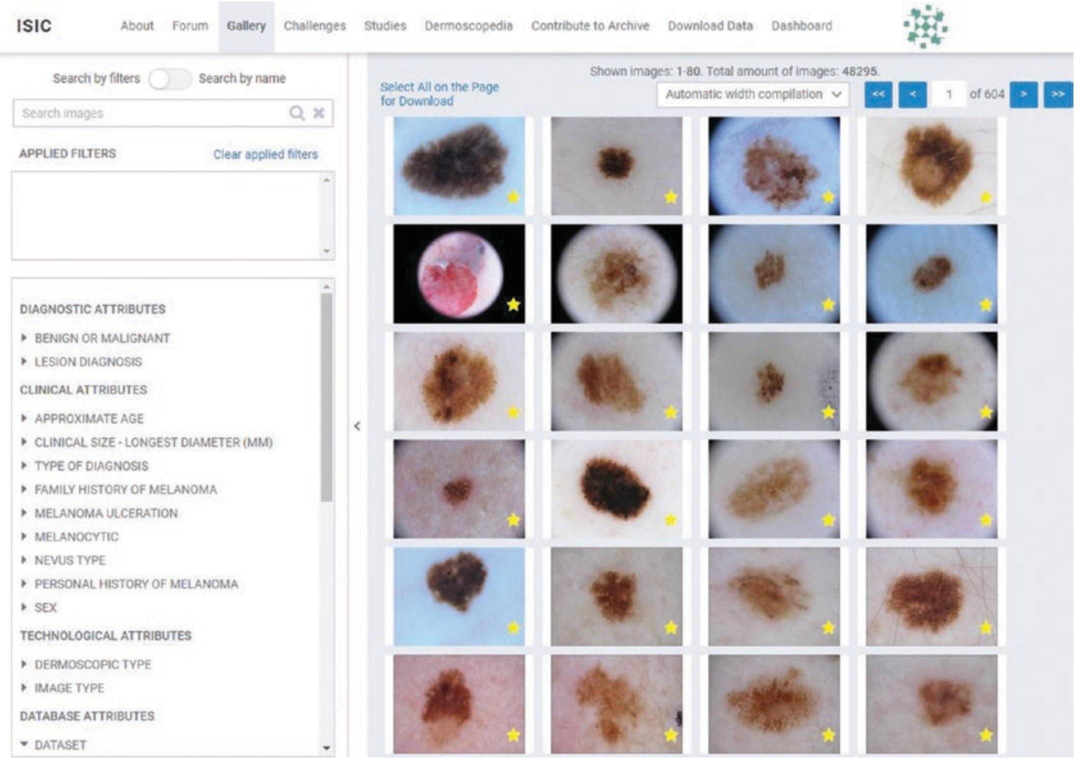
As opposed to the previous category, these archives are open-access and free to use. They vary in number of images, and some public archives include tens of thousands of images. A high percentage of these databases include images of malignant diseases.

In dermatology they include clinical, dermoscopic, and dermatopathological images of various skin lesions but mostly of skin growths (including benign and malignant tumors). Some, such as the MED-NODE databases (http://www.cs.rug.nl/~imaging/databases/melanoma_naevi), include a limited number of clinical and dermoscopic images, while others, like the International Skin Imaging Collaboration Archive (www.isic-archive.com), include many different diagnoses and tens of thousands of clinical and dermoscopic images. Another example is the University of Michigan Virtual Slide Box (https://www.pathology.med.umich.edu/slides/search.php?collection=DermPath&dxview=show), which offers dermatopathological images tagged with their diagnosis.

One of the best examples of a free database outside of dermatology would be the “Alzheimer’s Disease Neuroimaging Initiative” in the field of neuroradiology (http://adni.loni.usc.edu/). It is an initiative aimed at promoting the early detection of Alzheimer's disease, and it includes a large database of both MRI and PET images that are free and publicly available. Additional examples include the Duke University Medical Center Library and Archives (https://guides.mclibrary.duke.edu/c.php?g=158151&p=1035731) and The Cancer Imaging Archive (http://www.cancerimagingarchive.net). Updated lists of additional open-access medical imaging databases can be readily found online.

37.2.4 ISIC Archive

The International Skin Imaging Collaboration (ISIC) is a combined academia and industry effort aimed at improving melanoma diagnoses and reducing melanoma mortality by facilitating the application of digital skin imaging technologies. Aside from developing proposed standards on subjects such as terminology and medical imaging technologies and techniques, ISIC maintains the largest publicly available image archive of skin lesions. Currently, the ISIC Archive includes over 40,000 clinical and dermoscopic images of 13 different skin lesions diagnoses including melanoma, nevi, squamous cell carcinoma, basal cell carcinoma, etc. Most images are tagged with a diagnosis vetted by leading skin cancer experts, and some images have additional metadata, such as histological features of the tumor, skin type, age and sex of the patient, and more. A subset of the dermoscopic images in the archive include annotation for the specific dermoscopic features identified in each image. To make the archive comprehensive and ensure minimal bias, the images on the ISIC Archive are collected from different centers around the globe using a variety of devices within each center. After the images are collected, they undergo quality and privacy assurance before being uploaded to the archive. All images on the ISIC Archive are free and available for everyone to view and download (Fig. 37.1).



Shown images: 1-80. Total amount of images: 48295.

Fig. 37.1 ISIC archive website, image gallery page. Note the filters on the left side of the screen that allow for a detailed search based on lesion diagnosis, age, sex, etc. (Reproduced with permission from the International Skin Imaging Collaboration (ISIC)), https://www.isic-archive.com on 02/13/2018)

37.3 Machine Learning and Imaging Archives

As mentioned above, one of the major drivers for the creation of large image databases tagged with "ground truth" diagnoses is to allow for the development and training of ML algorithms capable of diagnosing medical conditions based on images.

ML is mathematically modelling the relation between the data (e.g., medical images) and the task (e.g., diagnosis) while optimizing a given penalty (e.g., accuracy of diagnosis). Deep neural network-based methods have gained popularity in recent years due to their high representation and classification power. In addition, the availability of advanced computing hardware and the vast amount of digital data enabled investigators to train neural networks that can model complex relations between given training data and tasks. In particular, diagnostic analysis of medical images provides an incredible opportunity for machine learning to impact clinical care.

In dermatology, since 2016, the ISIC Project has held annual challenges for developers, encouraging them to submit their ML algorithm. The algorithms are trained and tested based on their ability to provide a diagnosis for the lesions depicted in the archive images. Each year, the challenges are more complex and include more types of lesions than the last. The algorithms' performance improves every year, and while the 2016 challenge algorithms had a sensitivity and specificity similar to that of dermatologists [3], in the 2018 challenge, the algorithms performed better than the dermatologists in 97% of the times [4].

There are multiple similar challenges in other fields of medicine. Most them are focused around either analyzing images from different radiology imaging modalities (e.g., CT scan, MRI, ultrasound, X-ray) or analyzing images of histopathology slides and generating a diagnosis, prognosis, treatment adjustment, etc.; an updating list of imaging based ML challenges can be found on https://grand-challenge.org/challenges/.

37.4 Limitations, Challenges, and Risk of Bias

Be it for teaching and learning purposes, research or the development of diagnostic tools, imaging archives face major challenges and may be at high risk of bias if not planned correctly (Table 37.1).

Table 37.1 Challenges and risk of bias faced by imaging archives

Privacy	As dermatological imaging may involve photos of naked patients, maintaining the patients' privacy can pose a major challenge. Even when storing patients' images in closed and secured systems, some have raised concerns and argued that written consent should be obtained [5]. This, of course, is even more challenging with open-access public imaging archives
Security	Cyber security is less of a problem for public open-access databases, but it poses a major challenge for private closed systems as these may include protected health information (PHI) such as names and birthdates or even images depicting faces or tattoos that can be used to identify patients
Copyrights	If doctor **X** took an image of a lesion on patient **Y** while seeing him in medical center **Z**, who is the owner of this image (X/Y/Z)? Copyright issues pose a major challenge for imaging archives and are a matter of continuing debate. In addition, different images can have different licenses, thus limiting the use of images, even in open-access and public archives, for the development of computed diagnostic tools
Standards	Currently, most dermatological image acquisition is non-standardized with regard to the device used, lighting, camera angle, zoom level, color calibration, etc. This makes the comparison and reproducibility of images challenging. There have been attempts to generate standards for medical photography [6], but these are complex and require substantial time and resources to implement. Other specialties such as radiology have more fixed image acquisition standards
Metadata	Metadata is text-based information that describes the image. It includes information about the patient (age, sex, etc.), the lesion ("ground truth" diagnosis, location, evolution, etc.) and the image acquisition (type of camera, zoom level, etc.) [7]. Some specialties, such as radiology and dentistry, already have clear cut standards for metadata. In dermatology, the vast majority of imaging archives do not include any metadata, and this may decrease diagnostic accuracy and generate bias as two lesions that appear similar in an image can have a very different meaning in different clinical contexts (Fig. 37.2)

Table 37.1 (continued)

"Ground truth"	In the majority of medical conditions, the "ground truth" diagnosis is determined by the pathological report. However, histology interpretation is reader dependent, and different readers may provide different diagnoses for the same lesion. The inaccuracy of the "ground truth" diagnosis hampers the ability of the archives to be used for teaching or for the development of diagnostic tools. In addition, some benign lesions are rarely biopsied (e.g., cutaneous cherry angiomas), which means that they either will not be represented in imaging archives (see below) or that their "ground truth" diagnosis will be based on clinical impression alone, which may increase the risk of inaccuracy
Lack of generalization	*Skin lesions*: While there are over 3000 different diagnoses in the field of dermatology [8], most imaging archives include large numbers of images on a very limited number of diagnoses or very few images on a large number of diagnoses. In order to be clinically relevant, the images in an archive that is used to train physicians or ML algorithms to diagnose skin lesions must accurately reflect the spectrum of findings found in their respective clinical settings (Fig. 37.2) [9]
	In addition to addressing the full spectrum of relevant diagnoses, dermatology imaging archives may be subject to bias if they do not include *the entire spectrum of skin types, geographies, cultures, and disease distributions*. As the same skin lesion can appear differently on different skin types (Fig. 37.3) and most current imaging archives include a high proportion of light skin images, individuals or algorithms trained using these archives may not perform as well in real clinical settings that includes all skin types [10]

Fig. 37.2 Dermoscopic image of a nonpigmented Spitz nevus on the skin of a young child. Had this lesion appeared on the skin of an elderly individual, a biopsy would be recommended to rule out malignant melanoma. This is an example of how different clinical contexts may lead to different diagnoses even though the two lesions have a similar appearance

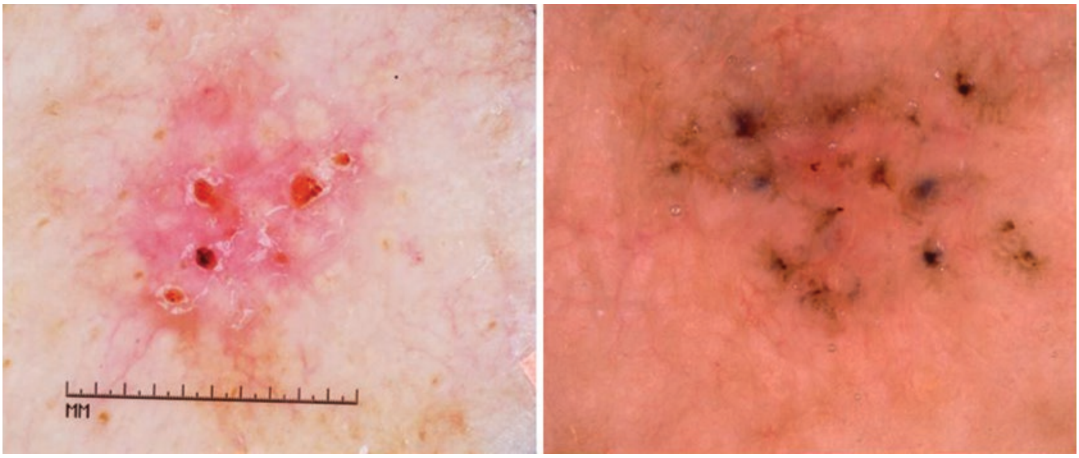


Fig. 37.3 Basal cell carcinoma (BCC) in light and dark skin individuals. In lighter skin types, BCC usually lacks pigment (left image), while in darker skin types, BCCs tend to be pigmented. This is an example of how a lesion with the same pathological diagnosis can have different appearances on different skin types. Reproduced with permission from the International Skin Imaging Collaboration (ISIC), https://www.isic-archive.com on 02/13/2018.

37.5 Future Considerations

As medical photography gains in popularity among dermatologists and other medical professionals for documentation, follow-ups, and other purposes [1], the number of medical images is expected to increase dramatically over the next few years. This trend will make it possible to create much larger and more comprehensive imaging archives.

The development of imaging and metadata standards by organizations such as ISIC and Digital Imaging Communication in Medicine (DICOM) for more and more medical specialties will allow for improved acquisition, storage, and tagging of medical images. The format proposed by DICOM, for example, includes two components: the first is text-based metadata describing the patient, study, acquisition, and image attributes, and the second is the pixel data of the image [6].

Together, these trends along with the resolution of regulatory and legal issues will lead to the generation of large, comprehensive, and accurately tagged and detailed image archives that can be used for research, teaching, and automated diagnostic tools in the future such as ML. As a result, ML algorithms are expected to become more accurate and more comprehensive. It is still unclear how ML technologies will be incorporated in the clinical settings, and while some raise concerns that ML will replace physicians, it is more likely that these technologies will be used as a diagnostic tools in the hands of physicians.

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Submitting Images for Publication

38

Viktoryia Kazlouskaya, Corinna Psomadakis,
and Daniel M. Siegel

Contents

38.1 Introduction

Images are integral part of contemporary scientific publications. They allow the reader to visualize results of scientific experiments, see clinical presentation of a condition, and track changes after treatment. They offer a visual proof of the claims made in the paper.

Journals may have slightly different requirements for the submission of image material, but there are some general recommendations that one must follow to prepare and submit their photos. The process of image submission may be divided into several steps:

1. Obtaining appropriate images reflecting the purpose of the study or case report.
2. Selecting images and adjusting them according to the requirements of a particular journal. Adjusting the images does not refer to "Photoshopping," but rather cropping, rotating, or annotating. Permitted photo adjustments will be discussed below.
3. Providing detailed information about the image in the figure legend.

38.2 Obtaining Appropriate Images

When obtaining medical photographs, one should develop the habit of shooting high-quality images from the outset, as it may not always be possible

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(and it is not a good idea) to alter images after they were taken. This is especially prudent for those working in academia or interested in scientific publications. For practical reasons, it is generally uncommon in most settings to have a professional photographer or studio setup available, but following some simple rules may help to obtain good quality images in general practice.

When taking pictures of a patient or an object, one should consider what they are intending to document. The area of interest should be located in the center of the image and be in sharp focus [1]. If the whole object needs to be captured, the image should be obtained from a greater distance; however, if only a closer view of a discrete site is relevant, it is better to photograph from close-up or using the macro image settings of the camera. Every camera has different schemes for macrophotography, and readers are encouraged to familiarize themselves with their camera's manual or visit a website that offers a walkthrough of the system in their reviews (e.g., www.steves-digicams.com) (see other Chaps. 12, 21). The now universal flower symbol denotes a macro mode. If close-up photos are taken, they should be perpendicular to the skin with the entire field in sharp focus. However, if the purpose of the photo is to demonstrate elevation or atrophy, a lateral or oblique view may be preferable, and one should capture the angle that best represents the salient clinical features, in whichever manner emphasizes them most effectively.

With regard to specific anatomical sites, when taking a photograph of the face, a few standard poses deserve mention. A front face photo, with the nasal tip parallel to the tragus and fully occupying the viewfinder and vertically oriented, will allow for reproducibility of images and enable valid assessments over time. Using a standardized side vantage perspective with a parallel tragus-nasal tip line would achieve the same reproducibility. Hands and feet may be photographed singly or in pairs.

If the manuscript discusses treatment results and requires before and after images, it is better to submit images that use the same angle, same room, same light source, and consistent framing of the photographed area if possible [1, 2]. Any postproduction adjustments to the images should also be the same if they are needed and clearly described in the text or figure legend. If any adjustment is done at all, we recommend the original images (which should always be kept) be submitted to the journal as supplemental material so a reviewer can make the judgment as to whether the submitted image is an honest representation of the claim being made by the author.

Even slight changes in positioning of a patient, change of lighting, or presence of a slight smile may optically distort (elongate or shorten) some parts of the face and can alter our perception of images (Fig. 38.1) [3, 4]. One study evaluated photographic variables using images taken with different settings during the same time and found that different lighting and use of makeup are two of the most significant parameters that influence image perception. They may even make the viewer believe that changes are more significant than they are in reality [5]. Those tricks are sometimes used to deliberately create "improved" posttreatment images.

The object of interest should be photographed against a neutral background with adequate light. It is important to ensure no additional objects are visible, such as clothing, jewelry, or room furniture, unless these are related to the disease (e.g., short sleeve shirt with a reaction in sun exposed areas, contact dermatitis under jewelry). Taking several images from different distances and angles, as well as using different light sources, is preferable and allows for the best image to be chosen afterwards. Additionally, if using flash, it is helpful to note a single point source of light results in the most shadow while a ring flash eliminates shadow. Shadow may or may not be useful in demonstrating a clinical finding and honestly showing outcomes. Most new cameras feature internal software and hardware that will automatically modulate flash output to avoid washing out images, but one should test for this capability before buying a new camera.

Many patients have distinctive landmarks such as folds, creases, telangiectasias, or scars that can be used descriptively to locate key features. If the photographer decides to mark a lesion with a colored marker, it is better to obtain unmarked images first to avoid losing said landmarks under a layer of ink.

Fig. 38.1 The above images illustrate the point that changing a subject's facial expression, or the amount of light in the photo, can drastically change our perception of the image. All images of the model were taken over a span of a few minutes with the same camera and from the same distance

One of the authors (DS) has always used a paper stick-on ruler with the patient's name in the field for subsequent identification, which can be blacked out or cropped as appropriate. If the face, or a recognizable part of the patient is being photographed, it is essential to obtain written permission from the patient to capture and publish the image. Some journals require that their own consent form be completed. Even if a journal does not require it at the time of submission, a consent form should be obtained and carefully saved in the event it is needed in the future. Additionally, the journal should be notified about any unusual conditions mentioned in the consent form. For example, patients may have specific wishes such as having their eyes covered, in which case the image should have the eyes redacted prior to submission. Of course, covering certain areas is not always going to guarantee the image is anonymized [6, 7].

Although having a professional digital camera is the surest way to obtain high-quality pictures, cheaper and smaller electronic devices (such as smartphones or tablets) have cameras that are generally adequate for the job. The device's settings, whether the device is a smartphone or digital camera, should be programmed to obtain high-resolution pictures, as most publications have a minimum image quality requirement. This requirement is typically 300 dots per inch (dpi) or higher for final submissions.

Resolution of an image is a term defining how much detail it has. Resolution may be measured in different units, the most popular ones being pixels per inch (ppi) and dpi. While dpi and ppi both describe resolution, dpi refers to print density on paper, while ppi describes pixel density on the screen. Increasing resolution after the picture has been taken may result in losing image quality and may constitute unacceptable image alteration [8, 9] (Fig. 38.2).

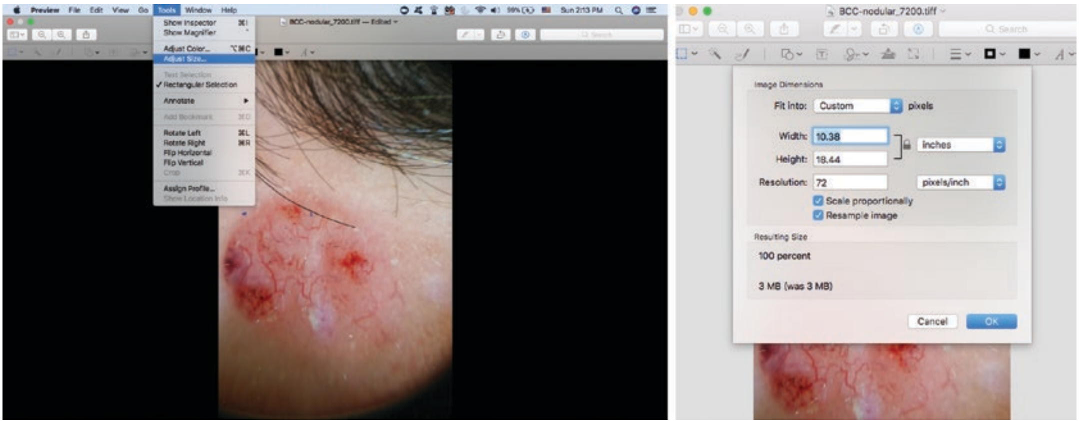
38.3 Selecting and Adjusting Images

Many journals explicitly discourage adjusting the image quality retrospectively [10]. If it is necessary to increase resolution, it should only be done while also decreasing the image size proportionally [8]. These "corrections" are available in almost all image editing computer programs (Fig. 38.3).

Certain settings may interfere with the image. For example, enhancing, color correcting or accentuating, and brightening scenes are ways to devalue data. Long exposure settings may cause the image to be too bright, which makes smaller details undetectable in the final image. Long exposure also results in the blur that is seen from movement of the patient or photographer with slow shutter speeds. Similarly, oversaturated detectors in fluorescence microscopy imaging may be appealing to use because the affected area looks brighter in the image; however, it may lead to the loss of information, which is referred to as a washed out area [11].

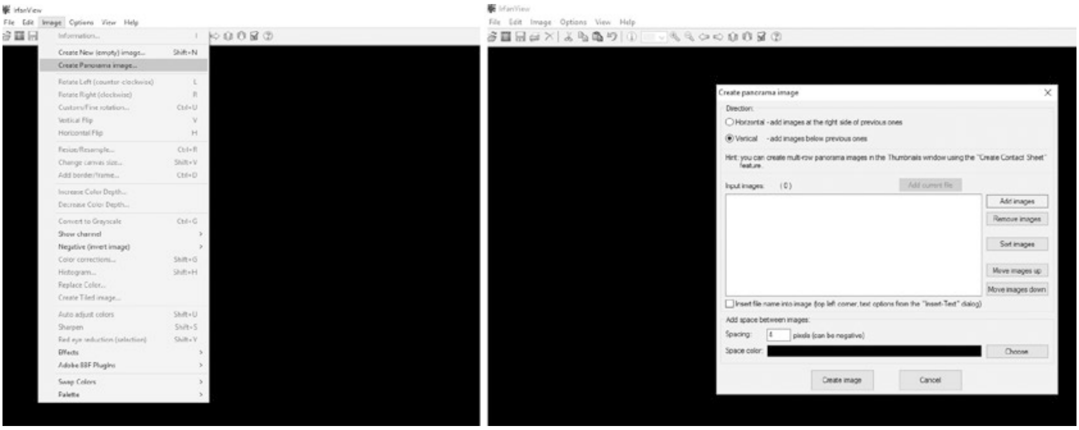
Ideally special cameras should be used when taking macro images from a microscope (pathology slides, electron microscopy, etc.), though inexpensive smartphone-compatible attachments allow imaging through an eyepiece attachment (e.g., ProScope Micro Mobile Digital Kit) that are adequate for teaching and lecturing purposes. Photographs of imaging

Fig. 38.2 Images with different resolution and same size. The upper image has 1 ppi resolution, and details of the image are hardly recognizable. The medial image has 5 ppi resolution, which is an improvement, but the details of the hyperpigmentation are still not clearly visible. The lower image has 72 ppi resolution (initial image), and surface skin changes are easily identifiable in this picture



Fit into: Custom pixels
Width: 10.38
Height: 18.44 inches
Resolution: 72 pixels/inch
☑ Scale proportionally
☑ Resample image
100 percent
3 MB (was 3 MB)

Fig. 38.3 Changing the resolution of an image in Preview (Macintosh). (**a**) After opening an image file choose “Tools” and “Adjust size.” (**b**) In the following window, customize the size and resolution



Direction:
○ Horizontal - add images at the right side of previous ones
● Vertical - add images below previous ones
Hint: you can create multi-row panorama images in the Thumbnails window using the "Create Contact Sheet" feature.
Input images: (0)
☐ Insert file name into image (top left corner, text options from the "Insert-Text" dialog)
Add space between images:
Spacing: 4 pixels (can be negative)
Space color:

Fig. 38.4 Creating a panorama image with IrfanView. (**a**) After opening IrfanView, click “Image” and “Create Panorama Image.” (**b**) In the following window, you may select type of panorama (vertical or horizontal), adjust color and width of dividing line, and insert files

procedures (X-rays, magnetic resonance imaging (MRI) scans, computer tomography (CT) scans) ideally should be captured and stored by radiology software; these native digital images should be the ones submitted for publication. Taking screenshots or photographs of an X-ray wall viewer should be avoided as it significantly compromises the quality of an image [12]. Radiology uses the data tagging standard DICOM, which contains all the relevant image information (patient identifiers, technology used to obtain the image, etc.) [13].

Many journals limit the number of photographs the authors can submit depending on the type of article. As such, one should only include relevant ones that best reflect the clinical and, if necessary, laboratory findings. If the author wants to include a larger number of images, some journals make it possible to create a composite image or panorama image by merging several individual photographs. Other journals may allow linkage to additional still images or videos, and each journal is usually explicit in what can be submitted. Multiple programs, including IrfanView for Windows (our longtime favorite), Image J, Photoshop, Lightroom, and Google Photos to name a few, may be used for this purpose (Fig. 38.4).

If creating a composite image, one should read through the journal's image policies, as they may require the submission of each individual original photo in addition to the composite. Other publications, for example, *Nature* and *Journal of the American Medical Association (JAMA)*, require that individual photos are clearly indicated by adding a dividing line between the component images [10, 14]. Some journals, however, may explicitly prohibit the creation of such panorama images.

Online-only journals usually permit a greater number of images, and such publications may be preferable to authors of papers with many relevant images. Online-only journals, or online-only articles of print journals, may have different rules for image submissions. For example, *Nature* allows a maximum of 300 ppi or 10 MB for online-only images, as larger files could affect the webpage's loading time [10, 15].

JPEG and TIFF are two of the most widely accepted image formats for submission to publications. TIFF is generally preferred because it does not lose image quality even when the file is compressed (lossless compression) unlike JPEG [9]. JPEG files, however, are generally smaller and are ideal for image storage. It is possible to change the file type in almost all image viewing programs though conversions to lossy compression formats such as JPEG will result in image degradation. Many cameras typically default to JPEG capture but will allow the user to change to TIFF format in the setup menu. The downside to native TIFF capture is that the images may be many times as large and can take longer to transmit electronically, as well as deplete storage space if that is a potential limitation. Keep in mind that an image captured in a minimally compressed high-quality JPEG format does not degrade with opening and viewing it. However, editing the image in any manner and resaving it will cause loss of data.

In the digital era, it is very simple to enhance images with various software programs. The pressure of obtaining and publishing results as quickly as possible to gain a promotion, acclaim, or other benefits may push scientists to manipulate images. Such attempts to create perfect images have been given the term "beautification" [16]. While the images may end up looking better, some forms of image manipulation can create inappropriate changes in study results and would be classified as a form of scientific misconduct. Today, cases of image manipulation account for about 70% of the misconduct cases handled by the US Office of Research Integrity (ORI) [17]. In order to address this trend, more and more journals have started using software to detect whether submitted images were altered with Photoshop [18]. *Journal of Cell Biology* reported that with the help of this type of software, signs of image manipulation were revealed in about 25% of submissions, with 1% being fraudulent [19, 20]. *Molecular and Cellular Biology,* which uses similar software, also detected a much higher incidence of manipulated images than their study anticipated, and thought it may result in numerous retractions of archived articles [21, 22].

Accusations of scientific misconduct may be devastating for scientific careers and result in widespread consequences, such as loss of position and reputation, getting banned from conducting research and applying for grants, and even financial charges. *Nature Cell Biology* retracted several papers authored by Sawada M. due to image manipulation of western blots. As explained by the author, he was under pressure to create images quickly, and he wanted the data to look clear. Although the authors were able to provide initial images, and the results of experiments were not questioned, the articles were still retracted purely because of image manipulation [19, 23–25]. The scandal with Hwang is another example of scientific misconduct with devastating consequences for the scientific community as well as the individual [26]. As was found after publication, two articles authored by Hwang et al. in *Science* included multiple instances of misconduct, including falsification of data and image manipulation [27–29]. The *Journal of the American Academy of Dermatology* retracted an article from 2010 based on evidence that one of the study's images had been digitally altered [30, 31]. In this case, before- and after-treatment photos of a plantar wart showed an identical foot suspiciously positioned in precisely the same position against a floral background, with the only difference being the plantar wart was not present in the second photo. As the senior author later explained, the article was submitted without her final approval (the signature on the submission form did not belong to her), and the photographs were not taken from the investigation group [30].

In order to increase awareness and educate researchers on the issue of image manipulation, ORI created an online learning tool which discusses 12 ethical principles of image use (Table 38.1) [32].

In addition to cautioning against image manipulation, it is important to note some key adjustments that are generally acceptable to journals. Adjusting the brightness and contrast is the most simple appropriate technique of image adjustment (Fig. 38.5) [11]. Auto settings should usually be avoided, because they tend to overprocess the image [11]. Correcting an image so that it represents what was seen in the clinical setting is acceptable in many situations as the goal is to share an accurate record of what was observed. It is not acceptable when used in the context of treatment response where manipulation may, for example, remove erythema in a clinical trial or wrinkles for an aesthetic procedure.

Using a histogram manipulation aid such as Photoshop's Levels tool to improve an image is often acceptable. The Levels tool corrects tonal range and color balance at the same time. The darkest color of the image is remapped as black and the lightest as white, which significantly improves the contrast of the entire image [11]. Gamma adjustment is a nonlinear adjustment that reflects the manner

Table 38.1 Ethical principles for the appropriate use and manipulation of scientific images, adapted from online learning tool for research integrity and image processing [32]

1	Treat images as scientific data
2	Always save the original image
3	Making simple adjustments to the whole image usually is acceptable
4	Cropping the image for the purpose of better representation of an object is usually permitted
5	Images that are created to be compared should be obtained with similar technical characteristics
6	Manipulation or adjustments of only parts of an image are questionable
7	Use of filters may change the image data
8	Cloning or copying and pasting of objects in the image is not permitted
9	Intensity measurements of fluorescence or immunohistochemistry images should be standardized
10	Formats that do not lose image quality should be used to store data. The reader should appreciate that if an image is captured as a JPEG initially, it is already compressed in a lossy but often acceptable manner. Opening and closing the image does not alter the image, but any editing and saving of the altered image may result in further loss of information
11	Use a scale for macro images when appropriate
12	Resizing of an image after it was acquired may lead to image distortion

Fig. 38.5 Initial image on the left. Adjusted brightness and contrast in the right

in which humans perceive light and color, and its use is permitted in most cases. Adjusting gamma would work on mid-tones, as such positive gamma (more than 1) will increase the intensity of mid-tones and negative gamma (less than 1) will decrease them. The use of gamma and level adjustments should always be mentioned in the figure legend, as well as which software was used to perform those changes [33]. This would not be considered acceptable when demonstrating aesthetic outcomes where pigmentation is an issue as the picture may not represent the true color of the patient's skin.

Another example of an acceptable adjustment is image cropping. This can improve a composition and remove irrelevant information, as when cropping an object from a distracting background or removing irrelevant peripheral objects (Fig. 38.6). At the same time, image cropping in order to hide information or manipulate study results would not be acceptable image adjustments. It is crucial that the original image is of a high-enough resolution such that cropping does not result in a blurry image [11]. In such a case, it would be better to retake the image with higher magnification. The best cropping technique is adjusting the image in the viewfinder before activating the shutter.

Alteration of any individual part of an image, combining images from different photographs, or concealing information in the image in order to manipulate data are all generally forbidden [11]. Digital image filters are also not appropriate as they change the intensity value of all pixels. A technique called dodging and burning, (a term that goes back to the film era and relates to selective illumination of a negative to "optimize" an image for the photographer's use) decreasing and increasing exposure, respectively, manipulates only some parts of the photograph and therefore is not advisable. Duplicating part of an image (e.g., with Photoshop's Clone Stamp tool) or using other common retouching instruments (e.g., eraser, brush, or blur tools) to clean the background is inappropriate. If those tools are used for the purpose of creating objects that were not initially in the photograph, they are considered to be falsification and misconduct.

If the author believes certain changes are absolutely necessary to achieve a better image but is unsure if they are permissible, such changes should be discussed with the journal editor upfront, and the original images should be submitted alongside the edited ones. The reader should keep in mind that if a journal has any concerns about the integrity of an image, they will likely ask for the file of the image before any adjustment. As mentioned above, it is of paramount importance to keep the original image files. The line between permissible image enhancement and what may be considered misconduct can be quite thin, so when in doubt it is

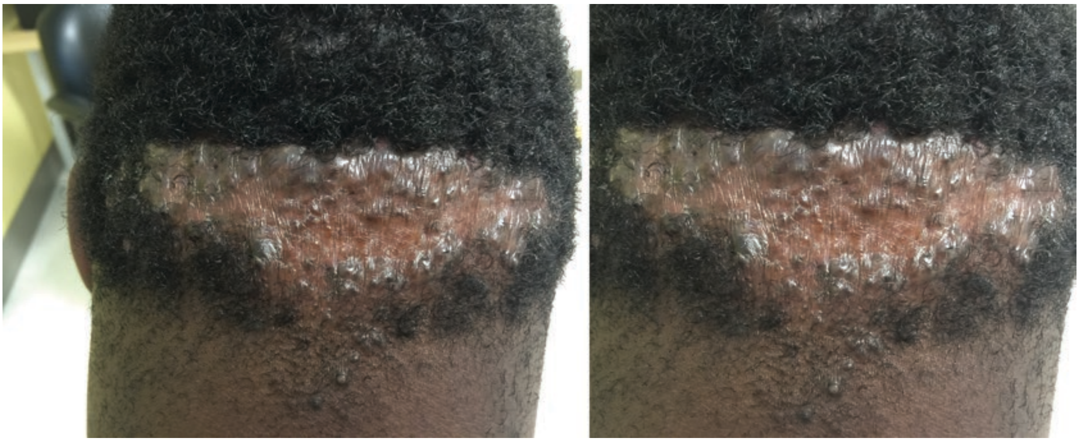


Fig. 38.6 Initial image on the left. Cropped image to remove distracting background on the right

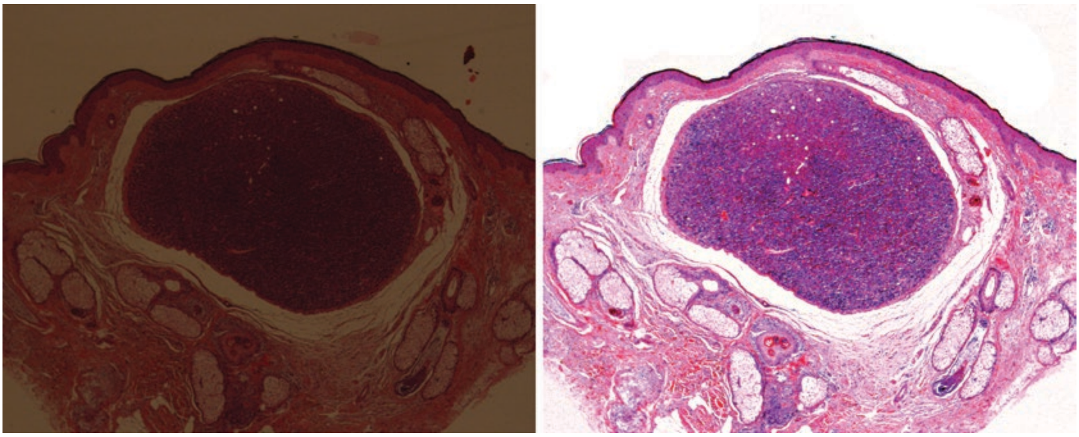


Fig. 38.7 Initial image on the left obtained from old histopathology slide. Adjusted image on the right with whitened background, changed levels, and imperfections deleted from the background. Although the adjusted image does not change the information presented in the initial one, there are many changes performed that should be discussed with the journal's editor. Initial images and slides should be kept as evidence

best to liaise with the journal editors for clarification. For example, even changing brightness in the whole photograph, which is generally permitted, may make cell signals or bands of western blots look brighter, and could make a well-intentioned photo submission appear deceptive (Fig. 38.7).

While it was shown that only 25% of authors keep original data, it is absolutely essential to do so [34]. Original files could be requested at any time of the review process or even later, and they serve as evidence. Keeping a hard copy of the images stored locally, in addition to a copy in a secure cloud, is an extra precaution to avoid data loss from computer crashes.

There are no unifying guidelines for submitting images to journals; therefore it is best to carefully read the requirements of each publication in question before submitting. Some examples are included in Table 38.2.

38.4 Providing Detailed Information in the Figure Legend

It is often said a picture is worth a thousand words; that many will not be necessary, but a few should be provided to give additional information about an image in the figure legend. Figure legends should accompany all photographs and contain precise information about the image (location of the image, camera equipment used, magnification settings in the case of macro images, etc.). The text of the article should also provide context that explains why the photograph was included, and a clear reference to the figure must be indicated. If a picture accompanies an original study or case series, the author(s) should mention whether it was taken from a study subject or from an external source merely to support the study findings.

Image type may require specific details to be included into the figure legends. When presenting radiographs, for example, position, the vantage of the exposure, body side, or point of respiratory cycle in chest radiographs should be mentioned. When submitting ECG photographs, the author should comment on when the test was conducted (e.g., at rest, Holter monitoring, stress test, etc.), as well as calibration of the ECG and labeling all leads. For magnetic resonance image (MRI), the strength of the magnetic field, pulse sequence, T1 or T2 weight, exposure time, decimation, axis of scan, gradient echo, depth of area of coverage, field of view, and resolution should ideally be reported [12]. For any image, the author should, in descriptions or captions,

Table 38.2 Image publishing requirements from the leading journals JAMA (Journal of American Medicine Association group); BMJ (British Medical Journal); NEJM (New England Journal of Medicine); JAAD (Journal of American Academy of Dermatology)

Journal	Final submission resolution	Acceptable formats	Color scale	Other specific requirements
JAAD [35]	300 dpi	Tiff, .jpg	RGB or grayscale	
JAMA [14]	≥350 dpi	.eps, .jpg, .pdf*, .ppt*, .psd, .tif	RBG	• Figure legend should be short (10–15 words) • Original magnification of microphotographs should be mentioned • Mention methods of digital processing • Marked and non-marked images should be submitted
BMJ [36]	300 dpi or higher at least 100% of the intended printed size	Pdf or JPEG preferred; TIFF, GIF, EPS, MPEG, AVI, MOV, and WAV files	Not stated	Minimal adjustment (color, sharpness, texture, or cropping) may be done
Lancet [7]	300 dpi 20% larger than intended print size	.psd, tiff, jpeg, .eps, .pdf, .ppt	Not stated	
NEJM [37]	1200 dpi	EPS, tiff, jpeg, psd	Not stated	
Nature [38]	300 dpi or higher	tiff, jpg, or psd	RGB preferred	• Minimal processing required • Keep original files • Mention software used for processing • Clearly mark borders of juxtaposing images • Positive and negative controls for electrophoretic gels and blots should be submitted

answer any question that they themselves might ask if seeing the image without such information provided.

An analysis of radiographs included in several major journal articles has shown that the majority of authors did not include information about the origin of the images, their selection process and representativeness, or technical details (e.g., if contrast media was used) [39]. Lang et al. proposed a set of six principles for documenting clinical and laboratory images in publications (CLIP principles) (Table 38.3) [40]. The principles are based on both ethics and common sense and may serve as recommendations for how to prepare images for publication.

Finally, if an image was obtained by a person other than the author(s), it should be stated or appropriately referenced in the figure legend. The image owner will need to give permission for its publication. If the image was previously published, permission will likely need to be granted from the publisher.

Table 38.3 The CLIP principles for documenting clinical and laboratory images in publications, adapted from Lang et al. [40]

CLIP principle	Explanation
1. Report the details of the subject of the image	Describe any relevant characteristics of the subject
2. Report the details of the image acquisition	Device and settings with which the image was obtained (brand, model, and settings can usually be found in the image metadata)
3. Report the details of how/why the image was selected	Mention if the image was taken from one of the subjects of the study, if it is a typical finding or extreme presentation, and why this image was selected as an example
4. Report the details of any image modifications	Mention any alteration of the original image
5. Report the important details of the image itself	Describe what the image represents and shows
6. Report the details of the analysis and the interpretation of the image	Analyze quantitative and qualitative data in the image

38.5 Conclusion

After reading this chapter, we hope readers can use the information to assist them in taking quality images that are appropriate for submission to journals. The majority of problems with inappropriate image acquisition and processing arise from the fact that many scientists are unaware of what is and is not appropriate. Therefore, raising awareness of what constitutes proper image manipulation and educating scientists are essential, and we hope we have aided in doing so. While mistakes may happen while obtaining and processing data, it is critical that study authors make a habit of critically evaluating final images submitted for publication [19]. Various organizations have been created in different countries (ORI in the USA, German Research Foundation in Germany, Danish Committees on Scientific Dishonesty in Denmark, and the Panel for Health and Biomedical Research Integrity in the UK) to help monitor for cases of scientific misconduct, including image falsifications. Journals should reinforce ethical guidelines for image processing and perform stricter audits of submitted images. It would be helpful to include at least one reviewer with knowledge of image processing when needed [41–43]. But most importantly, images should be treated as scientific data, and not as a tool to enhance the results of a study [2, 11, 44]. Maintaining a strict standard as a clinician or researcher, in addition to using the tips we outlined above, should ensure submitting images for publication becomes a seamless process, free of any unforeseen trouble.

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Storing and Manipulating Images

39

Paola Pasquali and Ramon Alberich

Contents

39.1 Introduction

From the very beginning of medical photography, doctors have taken pictures. Depending on the specialty, the setting, the country, the requirement of the institution, and other circumstances, patients were photographed either sporadically, continuously over the course of a medical condition, or as part of the routine documentation and academics: some examples are endoscopic studies, forensic medicine or dentistry, just to mention a few.

The number of pictures taken worldwide every day is exponentially increasing; the photographic process and storing media and formats are also evolving rapidly.

Patients are photographed as part of their medical documentation. As pictures are taken, a thorough storage system needs to be implemented if we want this information to be retrievable and accessible. Storage and preservation are as important as generation of information.

The actual tendency is to digitalize all images obtained and then stored by obsolete photographic processes and media (i.e., daguerreotypes, printed copies, and slides). Old photos have been converted into what we consider today

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the new process. Just by taking a quick look at the past, we can evidence the numerous changes in processes in just 180 years of photography; however, technology is changing so fast that today's state-of-the-art process could well be obsolete in a few years' time. Once a process/media/format is not considered state of the art anymore, reconversion into a new process/media/format needs to be considered. It's a never-ending race: from daguerreotypes to paper print, to microfilms, to magnetic diskettes, to resident hard disks, to dedicated servers, to the cloud, and so on.

For each process, there are inherent risks of loss. Time-related image degradation and loss of slides and paper prints are been substituted by threats on cybersecurity, hard disk failure, voltage/frequency instabilities, blackouts, and other nuisance. In the process, millions of images were lost. Many photographs have been lost because they were in supports that were devoured by time: foxing or browning of older photographs caused by fungal growth due to storing in damp places; reddish color slides with fungi spots; mold and bacteria grown under humid conditions; lost details, fading, and discoloration in photographs because of unstable chemicals in the resin-coated photographic papers [1]; or deterioration of light-sensitive gelatin emulsions of slides.

We lose our photographic material for many reasons: (a) inadequate storing and manipulation; (b) incorrect archival/retrieval system; (c) bad quality from the beginning; and (d) stolen storage (hard disks, computers).

Before taking a picture of a patient or a procedure, we need to ask ourselves the following questions: what do I need this for? Is it useful? Storing that image will take time and space. It requires cataloguing, retrieval time, preservation, and conservation. Preserving data requires effort, physical space, storing capacity, and cataloguing. This is all worth if the material is of good quality and useful.

Preservation, storage, and retrieval of photographic material are made possible nowadays through digitalization. This chapter will deal with digitalized photographs generated in the last 70–80 years, where the most common formats were slides and digital images. Other formats (e.g., paper prints and daguerreotypes) nowadays belong more to the field of medical librarian and conservators [2].

39.2 Why Do We Need to Retain Images?

In a recent paper, Mezrich and Siegel [3] make a concise list of why we need to store medical images. They summarize it as follows:

- To use images for comparison studies. We could include here the use in artificial intelligence (AI) systems that allow comparison for diagnosis and monitoring.
- As a defensive practice. An image can be a proof of prior existence of a medical condition.
- To satisfy State and Federal Requirements. Some legislation makes it mandatory to keep medical records, including images, for a specific period of time. It is important to mention that if a signed consent form to take an image is granted by a patient, the physician can be held responsible for not returning that image in the future. It cannot simply "disappear" from the medical record. These requirements are stricter when referring to images of mammography and not so established (yet) for a photograph of a skin rash or tumor. There is no clear-cut answer to this point yet. Specialties like radiology have nowadays clearer rules than dermatology. In some countries, there exist fines and other legal penalties for failure to retain files.
- To avoid the consequences of the "spoliation rule." Spoliation of evidence is "the intentional, reckless, or negligent withholding, hiding, altering, fabricating, or destroying of evidence relevant to a legal proceeding" [4]. As Mezrich states, "a jury will be entitled to presume that the missing evidence would be unfavorable to the party responsible for its unavailability" [3].

39.3 Digitalizing Medical Slides

Standard 35 mm film was introduced in the 1930s. Soon after Kodachrome, Ektachrome, and Agfacolor came out with what came to be known as slides or diapositives, physicians began to take photographs of their patients. As we have seen from the beginning of this book, the medical world has been always among the first to use photography for documentation. Reversal film is a type of photographic film that produces a positive image on a transparent base [5]. They were 2″ × 2″ slides framed in a paperboard or plastic profile and projected on a screen using a slide projector.

Most were kept in file cabinets or in plastic slide organizers that held up to 20 slides. These slides would sit in loose-leaf binders. These plastic slide organizers were unfortunately not always made of ISO standardized material, and the cabinets were not in cold and dry areas.

They were mostly organized following a numbering system by disease. The slide mounts often had the patient name also written in pen on the cardboard slide mount. Sometimes extra information like the allergen or medication that triggered the rash was written on as well.

Slide collections started to be built both in hospitals and private clinics. There was not a unique method of storage and cataloguing. Dark fading and yellowish staining became one of the commonest problems for slide photography (just as for paper and especially for color paper) [6]. Preservation and conservation details of slice collections will be dealt in the Chap. 39. It is important that only well-preserved collections be digitalized. One way of preserving slides is maintaining them in specially adapted cold and dry rooms. As this method is not very practical and not even part of a generalized knowledge, many collections have been irreversibly lost. For those that are still in good conditions, digitalization has become an excellent mean for preserving, improving, cataloguing, and retrieval. By digitalizing collections, valuable material is becoming available for study. By preserving, knowledge is also democratized. Digitalization has another important application: images can be used to feed artificial intelligence systems. One example is the experience of VisualDx [7], a diagnostic clinical decision support system that has taken up this challenge and is digitalizing important professional collections that would otherwise get lost.

Before starting to digitalize, a collection must be appraised. Its management encompasses four basic components: inventory, appraisal, cataloguing, and proper housing and storage [8]. Preservation of the original artifact together with the production of a digitally restored version may offer the best solution in some instances [9].

Inventory will give us information on number, on types of processes, if they are mounted or not, and in what type of casing they are.

Appraisal gives information of the conditions of the collection, its value for the use it is meant for, and an assessment of storage needs.

Cataloguing involves identifying all possible data retrieving keywords from the image.

Proper housing and storage is of paramount importance to preserve a slide collection. Slides are particularly sensitive to humidity. They deteriorate in high but also in very low and in fluctuation cycles. Ideally, they should be kept at 30–40% humidity. High temperatures speed up deterioration. They should be kept in cold rooms (less than 10 °C) to reduce mold growth. It is also important to keep in mind than when a slide is taken out of a cold room, condensation can cause damage. Many have kept their slides in plastic protective sheets. Digitalizing a collection can be the perfect opportunity to rehouse a collection into a better envelope or box. Enclosures need to be breathable. Plastic enclosures should be made of materials recommended by ISO standards [10]. At high humidity, slides can adhere to the surface and become damaged. A photographic activity test (PAT) was developed to test the quality of photographic storage materials. It is the subject of ISO Imaging materials that relate to photographic activity test for enclosure materials [11].

The previous standard ISO 14523:1999 describes the test as a “predictive test of interactions between storage enclosure[s] and photographic image[s]. It can also be used to evaluate possible photographic activity caused by components of enclosures such as adhesives, inks, paint, labels, and tape."

39.3.1 Scanning

Scanning a large collection requires an enormous amount of work. It should be done by personnel that know how to physically manipulate the slides as well as being capacitated to manage its content since medical material is a sensible material. The first technical consideration is the choice of scanner [12]. The film scanner needs to fulfill certain requirements:

- Batch scanning. Capacity to preload several sets of slides
- High-quality sensor records imagery
- Software to reduce dust, scratches, and spots
- Software to adjust color balance
- Software to reduce "noise" (grain)
- Pre-visualization of slides for selection and adjustments
- Software to include metadata

High-end scanners have become more affordable and recommended for digitalization of important material such as medical photographic collections.

Some professionals physically clean each slide prior to scanning, but the bulk of editing/optimizing takes place post-scan. Occasionally, they remount the film from a glass enclosure into a standard plastic mount—the older glass mounts protect the film from mechanical damage but can present a variety of other challenges like the potential for newton's rings as well as just a buildup of dirt/residue inside the mount.

39.3.2 Packing and Storing

Digital images need to be stored and classified. As the number of them is enormous, they will also need to be compressed to decrease storage requirements and/or accelerate their proper transmission. Image data compression is the method used to reduce the amount of data of the original image while maintaining the diagnostic qualities of the image.

The American Board of Radiology in his document of "Noninterpretive Skills Domain Specification and Resource Guide" [13] explains the two approaches to image data compression: it can be either lossy or lossless.

39.3.2.1 Lossy Compression

It is an irreversible form of compression. It is a form of compression that can permanently remove marginally important information. The compressed image is visually similar but not all the original data is stored. It allows greater ratio compressions.

The JPEG/JPG (Joint Photographic Experts Group) is among the most common lossy systems of compression. Its files are widely used, and most electronic submissions accept them as standard even if they lose a slight degree of image quality especially when amplified. This loss depends on the compression used when storing the images. Different degrees of JPEG compression are possible. JPEG compressions up to 1/20 of the original size result in images, which are adequate to manage later on (for visualization, printing, editing) (Fig. 39.1).

39.3.2.2 Lossless Compression

Decreases statistical redundancy in order to display data without loss of information. It is a reversible form of compression. Diagnostic information is not lost but compression is limited to ratios of 2:1–3:1.

Cameras use efficient image compression systems that allow the images to be stored, edited, retrieved, and/or transferred in files without losing photographic quality. Lossless file systems are TIFF (Tagged Image File Format) and PNG (Portable Network Graphics) files and also BMP and PNG (Fig. 39.1) [14].

39.3.2.3 No Compression

Another file format known as RAW is available in DSLRs, CSC (MILC or mirrorless) cameras,

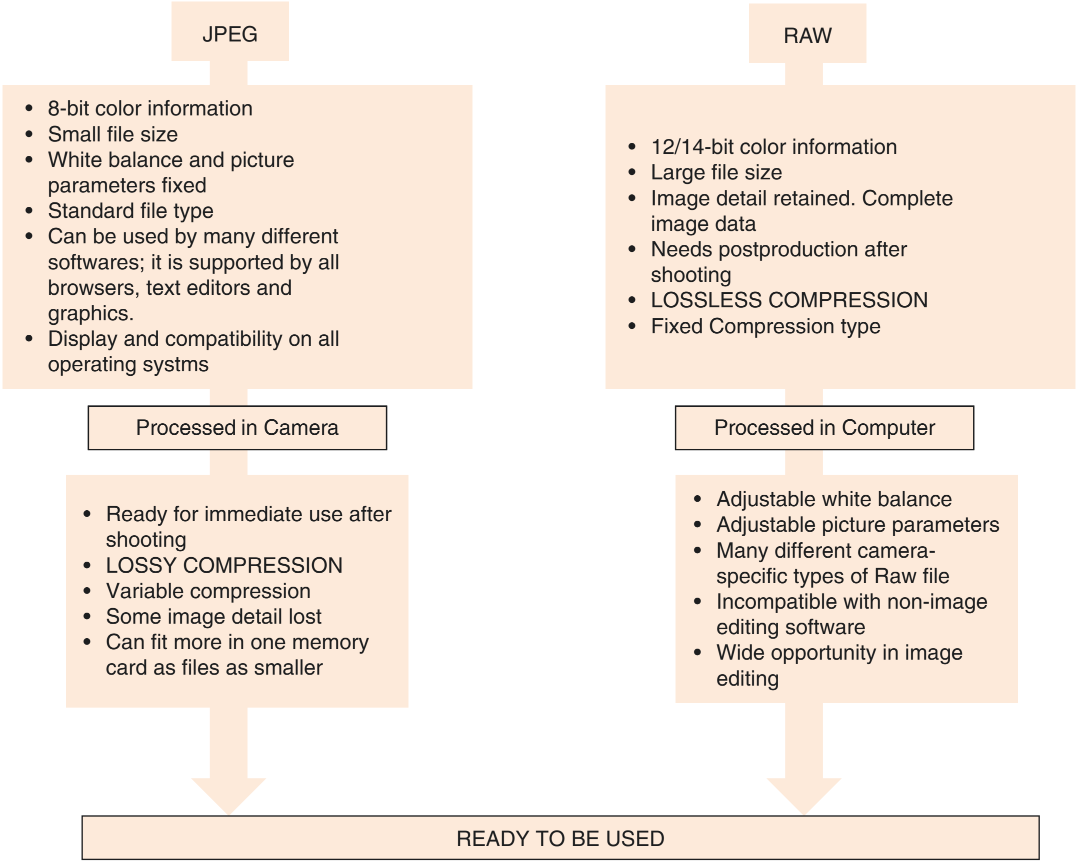

Fig. 39.1 Main differences between JPEG and RAW (Adapted from: Taylor, D. Exposure, An Infographic Guide to Photography. Ammonite Press, UK. 2016. 176 p)

Table 39.1 Differences between image formats

Image format characteristics				
Image format	Available colors	Compression	File size	Best for
RAW	Billions	No	Very big (<10 MB)	Editing
JPEG	16.1 million	Lossy	Small (<1 MB)	Websites and storage
GIF	256	Lossless	Small (<1 MB)	Animaiton
PNG	16.1 million + transparency	Lossless	Big (<3 MB)	Websites and storage
TIFF	Variable	Variable	Big (<3 MB)	Editing and printing
BMP	Variable	Lossless	Big (<3 MB)	_

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some bridge, and high-end smartphones. This type of file has the minimal processed data from the sensor. They are often called "digital negatives" since a RAW file has all the information needed to create an image but cannot directly used as such. The advantage of a RAW file is its higher image quality since pixels are not lost. However, its size can be up to six times bigger than when using JPEG (Table 39.1).

In order to develop RAW, a file computer software is required. RAW files are not processed by the camera processor. They are large and occupy a large storing space and contain a lot of information that can be edited.

39.3.3 Enterprise Imaging

Enterprise Imaging (EI) is defined as "a set of strategies, initiatives and workflows implemented across a healthcare enterprise to consistently and optimally capture, index, manage, store, distribute, view, exchange, and analyze all clinical imaging and multimedia content to enhance the electronic health record" [15].

For Roth et al. [15], it should include a decision-making body (governance), a strategic plan, a platform (infrastructure), a clinical imaging and multimedia content (what are the image taken for, how it is taken and by who), EHR (electronic health record) enterprise viewer considerations (where providers can add textual input in the context of ease-to- use-and-access images), and image exchange services to facilitate image sharing (internally and externally) and the capacity to share images and metadata to generate repositories of data for deep learning and neural networks (AI) (Fig. 39.2).

39.4 Image Editing Software

Photographs need to be stored and sometimes edited. There are many editing software packages available in the market. The most commonly used are Adobe Photoshop, CorelDRAW, and Adobe Lightroom. Editing software allows many adjustments such as resolution, image size, brightness, contrast, tonal range, dust and scratches' removal, cropping, and white balance.

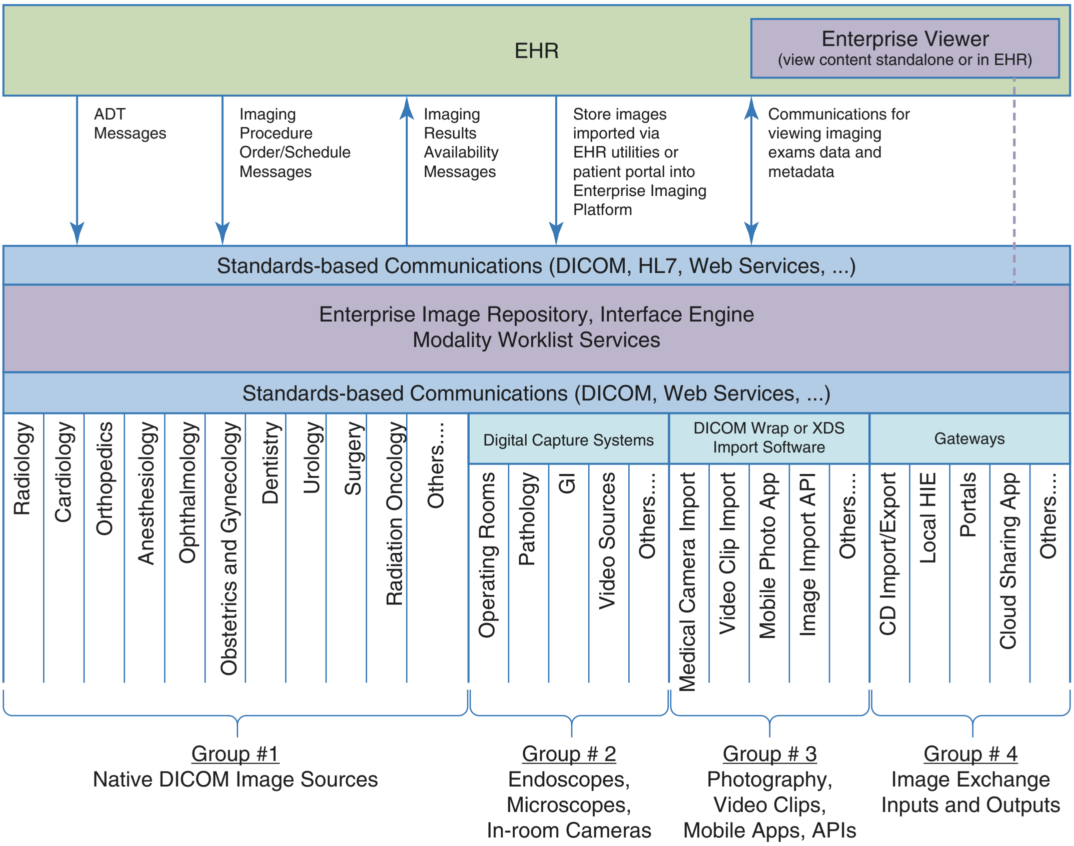

Fig. 39.2 An Enterprise Imaging platform provides the standard-based enterprise infrastructure to support departmental imaging workflows (From Roth CJ, Lannum LM, Persons KR. A Foundation for Enterprise Imaging: HIMSS-SIIM Collaborative White Paper. J Digit Imaging. 2016 Oct;29(5):530–8. With permission by Springer @ All Right Reserved)

In medical photography, editing software should be used solely to improve the aspect of the original image as long as these changes are ethically acceptable. The goal is to reduce issues that obscure clinical information especially those that regard color. Editing acceptable in medical photography is discussed in Chap. 37.

For storage and retrieval, photograph files include some basic metadata like date, time, camera model, and exposure factors. Other data will need to be included using PACS or editing software like Adobe Lightroom or Picasa. Keywords to later help retrieve cases can be added individually or by group of images (e.g., liposuction, Mohs surgery, etc.).

39.5 DICOM and PACS

When dealing with medical digital image storage, two concepts are important: DICOM (Digital Imaging and Communication in Medicine) and PACS (Picture Archiving and Communication System).

DICOM is the standard for the communication and management, storage, impression, and transmitting of medical imaging information and related data [16]. In a similar way as tags embedded in a JPEG file, a DICOM file (a DICOM object) can include a variety of items (e.g., name, ID, keywords, multiple images, and even videos) that cannot be separated one from each other. For example, a photo of a dermoscopy of a patient's tumor in the head may contain patient's name and ID within the DICOM file, so that the image cannot mistakenly be separated from a patient's personal information. DICON standard also facilitates interoperability by specifying [10]:

- A set of protocols of communication to be followed by devices claiming conformance to the standard
- The syntax and semantics of commands and associated information that can be exchanged using these protocols
- A set of media storage services to be followed by devices claiming conformance to the standard
- The file format and a medical directory structure to facilitate access to the images
- The related information stored on interchange media
- Information that must be supplied with an implementation for which conformance to the standard is claimed.

Each DICOM archive includes the format (JPEG/TIFF/RAW) and tags with the patient's administrative information. If a patient's image needs to be integrated in his medical record, it will need to be "dichotomized."

There are special applications (like Medical Images Organizer (MIO) [17], MicroDicom [18]) that convert an JPEG/TIFF/RAW image into a DICOM format.

PACS (Picture Archiving and Communication Systems) is instead a storage system that attempts to provide an economical storage, rapid retrieval of images, access to images acquired with multiple modalities, and simultaneous access at multiple sites [19]. It is a storage system which substitutes manual search, filling of information, and transport of images

DICOM is the format for the storage and transferring of PACS images.

Images become available with multiple modalities and from multiple sites; PACS is basically an image acquisition device, data management system, image storage device, and transmission network, display, and device to produce hard copy images [13]. There are no DICOM standards for dermatology yet.

39.6 Catalogue and Data Protection

The appropriate structure for organizing digital photographs on the computer is by using image data banks that can be integrated with clinical recording systems such as electronic medical charts. There are several commercial systems appropriate for dermatology available on the market.

A photo metadata refers to the text information pertaining to the image (either embedded into the file or contained in a separate file that is associated with it) [20].

This data allows information within the file to be understood by other software, hardware, and end users.

Metadata can be stored in two places:

- *Internally*: it is the one generated automatically by the device capturing the image like location (if camera is connected to GPS), date, format (JPEG, TIFF or RAW), number of image, and technical information (ISO, EV, f, speed, flash, focal distance, size, camera model, place of storage, white balance).
- *Externally*: it is the one found outside the image file in a digital asset management system (DAM) or by a "sidecar" file, such as XMP, or an external XML-based news exchange format file as specified by the IPTC [21].

The International Press Telecommunications Council (IPTC) [15] defines the three main categories of data:

- *Administrative*: identification of the creator, creation date and location, contact information for licensors of the image, and other technical details.
- *Descriptive*: information about the visual content. This may include headline, title, captions, and keywords. This can be done using free text or codes from a controlled vocabulary. In medical photography, one should use keywords that describe the content of the image (name of the disease, surgical procedure, treatment, hospital/clinic, ID, etc.).
- *Rights*: copyright information and underlying rights in the visual content including model and property rights and rights usage terms.

It's important that the metadata stored in an image file stays with the image. Metadata is essential for identification and copyright protection. Metadata are also key to smoothing workflow, easily finding digital images via search—online or offline—and tracking image usage.

All saved medical images should be catalogued meticulously with a tag system. The primary concern when storing medical data is cataloguing efficiently. It is also extremely important to maintain the privacy of the patient's data.

You should familiarize yourself with the system used by the health service or hospital in order to store its digital images. Likewise, knowing their policy for storing and sharing clinical image records is a must.

Managing medical images requires a close control on how these images are stored and shared.

39.7 Backup

Medical digital images should be transferred as soon as possible from the camera/smartphone memory card to the computer/Cloud. Once placed in a safe place, they should be post-processed as needed, catalogued, and stored into the medical record or "DICOMized" and uploaded into the EMR.

To comply with data protection laws and regulations, if a department decides to have photographs taken with smartphones, these images should be downloaded immediately to a secure server and erased from the phone. For this reason, some professionals even have a dedicated smartphone that is used only within the hospital premises.

The cost of hard disks has gone down in recent years, making even easier to store entire inventories in single spaces. Just as with cameras, computers, hard disks, and other electronic accessories should be keep in rooms with ambient temperature of around 72–73 °F (23 °C), away from direct sunlight and high humidity.

Hard disks need to be backed up periodically. Many hospitals have private and safe cloud space where images can be stored. All hard drives eventually fail through usage, defects, damages, and invasion, or they just become obsolete. Make sure you make safe copies and change hard disks as necessary. Likewise, personal computers can be stolen or lost, so it is crucial to back up tour image storage periodically in external hard drives which are bundled with backup software.

Before saving images, erase the ones that are equal (repeated) and technically incorrect (blurred, incorrect background, etc.). Keep only the ones that will serve the designated purpose. Do not waste time pretending to edit every photo. Even if they are few, leave only the good ones.

Not all photographs need to be of the highest quality. Depending on the use, you could compress many of your images into JPEG files in order to minimize space, as long as you keep safe the original files, not previously edited or cropped or renamed. Archive the original, the unedited master, and the edited version as TIF files and then create derivative JPG files as needed.

Originals are of great importance if we are ever faced with an audit of authenticity verification of the images or decide to use them for publication/lecturing/publicity.

39.8 Conclusion

Regarding storage and manipulation of medical images, it would be ideal—almost utopian—to have a single universal standard that everyone follows. Such standard should include aspects such as the accepted mode of storage, compression, and time to storage.

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40

Preservation and Conservation of Medical Photography

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and Paola Pasquali

Contents

40.1 Introduction: Medical Information and Documentation

Medical records (MR), most of them organized in what is known as the clinical history, are informational inputs of great value. They contain both medical and administrative information and are part of a personal and institutional history. As such, they have legal and academic importance. Their correct administration, management, and custody optimize the management, help protect the legal interests of the patient and of the health institution, as well as provide information for statistical, research, and teaching purposes. MR is part of our individual and collective memory [1].

Until recently, all the medical documentation was basically handwritten or printed on paper first by typewriters and later from printers. In some cases, they were accompanied with photographic images, printed or on slides, and with other images from noninvasive or minimally invasive techniques, especially X-rays.

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Each format has its own preservation and conservation challenges. Today's MR are mostly digital, but we have an immense accumulation of stored material in previous formats—especially on paper—that requires its preservation at least until it is transferred into formats of new technologies.

According to Caicedo [2], the predominance of textual documents in archival collections has been the main cause for not granting sufficient importance to preserve other forms of documentation other than traditional paper like plans, drawings, pictures, photographs, film tapes, recordings, X-rays, tickets, passwords, coupons, labels, stamps, and in general any movable object that has a representative or declarative character. Other less obvious materials related to the patient are inscriptions on tombstones, monuments, buildings, and the like. The spectrum of many patient's medical information is spread in many formats: from paper to digital; the latter, in EMR, hard drive disks, clouds, and computers.

Consequently, nowadays, medical documents are currently presented in both physical and digital media, and its preservation and conservation becomes one of the most important challenges for the health facility information unit (archive), since there are multiple factors that can alter and/or destroy them in different ways.

The aim of this chapter is to outline a set of theoretical and practical aspects of the preservation of MR independently of their support, as well as to present some guidelines and methods that allow controlling external agents that negatively influence their preservation. As medical photographs are included in the MR, it is sometimes difficult to separate one from another when approaching this topic.

According to Falagán and Nogueira [3], the first accounts of medical information are present back in the fifth century BC, at the time of Hippocrates, where there seems to have started the need to record in writing, with precision and order, the medical experience when facing individual illness. Traditionally, the concept of medical information has been associated with that of exclusively clinical information and clinical history, which has been classically defined as the complete or partial narrative of the doctor's experience in his relationship with a specific patient. This information used to be related to a pathological condition (pathography) of the patient; however, medical information has recently been defined as any data, whatever its form, class, or type, which allows to acquire or expand knowledge about the physical state and health. Any modality of health care, which is not the same as illness, gives rise to a care process, generating information and documentation that are integrated into a clinical history and need to be preserved, taken care of, improved, or recovered.

According to the *Conserjería de Salud del Hospital Universitario Virgen de la Victoria* [4], MR can be defined as the set of medical-legal documents in which the necessary information for the correct care of patients is collected, gathering information of assistance, preventive and social type, organized in a clinical history, which in turn becomes an instrument that guarantees the quality of the service provided to the patient, since both the documents and the information so organized are necessary for the determination of the doctor's medical diagnosis of patients.

This documentation referring to the health status of a person is linked to his/her life cycle and is produced from and before his/her birth and also (in some circumstances) beyond his/her death, so, for this to occur, two conditions are required: that there is a contact with a doctor and that the act is duly documented [3].

40.2 Theoretical Aspects on Preservation, Conservation, and Restoration of Documents

Díaz and Gámez [5] in their research work, "Guidelines for the preservation of the documents of the General Archive of the Faculty of Sciences of the Central University of Venezuela," specified the difference between three important terms related to documents, the conservation, preservation, and restoration:

- *Conservation*: According to Heredia [6], the functions of the archives include collecting, preserving, and serving. This term has two meanings from the archival and librarian point of view. Conservation of documents is a necessary measure that must be carried out in the archives in order to retain documents for periods of time, in the organization of different types of files, consolidated according to their life cycle. The International Federation of Library Associations and Institutions (IFLA) [7] defines conservation as the specific practice used to retard deterioration and prolong the life of an object by directly intervening in its physical or chemical composition. Therefore, conservation is a fundamental procedure to guarantee the perpetuity of documents over time, seeking to slow down the natural aging of the support. It is of great importance that the archives comply with certain guidelines for safeguarding the documents.

- *Preservation*: is a method that seeks to control the external aspects that can negatively influence the documents, for example, the place conditions where they are stored, the staff manipulation, the action plans, and preservation techniques and methods, among others. Preservation includes all administrative and financial considerations, as well as stipulations on storage and facilities, human resources, policies, techniques, and methods aimed at preserving the collections housed in archives and libraries and the information contained therein [7].
- *Restoration*: can be defined as the methods and techniques applied to the document with the purpose of achieving its recovery with the intention of guaranteeing its perpetuity over time. Viñas and Viñas [8] define restoration as the recovery of the document's physical and functional integrity, thanks to the correction of the alterations that it has suffered. Normally, restoration is carried out as a consequence of the document's deterioration, repairing the damages caused, which may be due to various factors, such as noncompliance or nonexistence of basic standards or guidelines of conservation and preservation. In turn, it can also be due to some external (environment) or internal (the medium on which the information is recorded) factor that accelerates the document's deterioration.

Therefore, preservation is consolidated as a global concept that includes both conservation and restoration and becomes an administrative task that fully affects the management of a library and/or archive [7]. *Preservation* seeks long-term results and includes prevention of all factors that may affect the well-being of the documents and the necessary measures for adaptation of the physical storage space, while the term *conservation* is focused directly on procedures and care that must be taken into account for the handling and guaranteeing of the documents' good state. On the other hand, *restoration* centers its attention on all those tasks that are intended to intervene directly in the document in order to restore its physical integrity, although not exactly original [9].

40.3 Preservation and Conservation of Medical Documents

As mentioned above, medical documentation is presented in different media/supports and formats, both physical (e.g., paper, cellulose, radiographic films) and electronic (CDs, memory flash, hard drives); therefore, there is a latent problem when defining unified guidelines that facilitate their preservation and conservation alike, since, depending on the support, each will have their own external and internal factors that influence their degradation. Aspects such as temperature and humidity will affect documents differently even though they are stored and grouped in the same clinical history (paper, cellulose, radiographic films, CDs, diskettes, etc.).

Even if new technologies have allowed health facilities to start using information systems, consolidating electronic medical records, where patient information is digitalized and stored electronically, preservation and conservation of documents refers mostly to the preservation of paper documents still generated nowadays and accumulated over the years, even centuries, and their need for conservation. The information related to paper deterioration and forms of preservation is presented, and later specificities of the other types of support will be indicated.

It is important to mention that not all material deserved to be preserved. The cost of doing so exceeds many times its value. Some material on paper support could eventually be copied to the new digital media with a multiple purpose: (1) reduce the archive spaces, (2) unify the systems of preservation and conservation, (3) facilitate their access to doctors, and (4) additionally also to facilitate researchers with a huge amount of information to work on. Indeed, one of the main means to preserve is by generating a facsimile [10]. It is important to distinguish between copies and originals. In relation to photography, it is important to know the most common photographic processes that were used since the beginning as each requires different preservation guidelines.

40.4 Photographs: One Format? Many Formats?

When referring to medical photography, we need to understand that photographs come in different formats. Medicine has been using photography to register medical conditions since its creation in 1839. Therefore, one can find medical photographic records in almost any support. Table 40.1 shows the different photographic processes.

A collection of medical photographs needs to be inventoried, appraised, catalogued, and finally properly housed and stored [11]. Appraisal will allow determining the value of the collection and the need for preservation. Not all collections are in conditions to be preserved, and sometimes the cost of preservation is greater than the value of the material. Once a collection is considered valuable (all or part), it can be converted into another format and the originals stored properly. Photographic material needs to be screened periodically. Each has a natural history of deterioration that can be slowed if conservation is correct.

Photographs typically have three components: (1) support (glass, plastic film, paper, resin-coated paper), (2) binder (gelatin, albumen, or collodion, which holds the image material to the support), and (3) final image material (silver, color dyes, usually suspended in the binder) [11].

Table 40.1 Some common photographic processes

Date	Photographic process
1839–1860	Daguerreotypes
1839–1860	Salted paper prints
1851–1885	Glass plate negative
1851–1885	Collodion wet plate glass negatives
1878–1925	Gelatin dry plate glass negatives
1889–1951	Nitrate negatives[a]
1850–1880	Albumen prints
1885–1905	Gelatin and collodion printed-out photographic prints
1880	Black-and-white gelatin developed-out photographic prints
1934	Acetate negatives introduced for sheet film
1935	Chromogenic color film and transparencies
1948	Instant black-and-white process
1960	Polyester film
1963	Instant color print process
1985	Electrostatic, ink jet, and dye sublimation prints

Adapted from: Roosa [20]

[a] Prior to “development” paper, contact printing was carried out using paper that darkened naturally when left exposed to daylight. It was called albumen printing paper. It required exposure to sunlight. Development papers like Velox could be handled before exposure even under weak electric light or yellow gaslight. It was discovered by Leo H. Baekeland in 1894, a Belgian chemist, who sold his discovery to Kodak. Baekeland discovered in 1907 the first plastic, named after him, bakelite

40.5 Factors That Can Deteriorate Photographs

It is necessary to ensure optimum environmental conditions from the moment in which the premises are built or adapted for an archive, including the ones in health institutions. The space environmental conditions must be controlled both in the premises where the documents are kept and in the working personnel offices, so that the preservation of the documents can be guaranteed while ensuring safety and healthy working conditions to the personnel.

There are factors that can determine damages to medical documentary assets. These factors are grouped into environmental, biological, natural or human-made catastrophes, chemical and finally other external factors. When referring to photographs, environment, storage, handling, and shelving conditions are determinants in their well-being.

When focusing specifically on photographs, (a) the *environmental factors* that can generate damage include relative humidity and temperature, light and air pollution (either by their fluctuations or by permanent action), and housekeeping practices. These can directly or indirectly degrade the different supports and registration techniques. Similarly, (b) *biological factors* such as microorganisms, insects, and rodents can alter and degrade the different supports [12]. Other types of factors that can destroy documents, called (c) *natural or human-made* catastrophes, are represented by floods and fire. We also find internal and external conditions to the document, (d) the *chemical factors*, related to the materials used to make the paper/support, as well as those archival tools employed to organize and install the documents, which could damage them when they degenerate or rust, and finally, we find physical factors caused by handling of the documents.

40.5.1 Environmental Factors

Environmental factors include temperature, relative humidity, lighting, and pollution. Paper, cellulose, color pigments, and other material degrade with time, and losses can be minimized if proper conditions are installed.

40.5.1.1 Temperature and Relative Humidity

The first aspect that must be understood about temperature and relative humidity is that there is no ideal level for all types of documentary materials, only values and ranges that minimize certain changes in materials and objects [7]. Both factors are determinants, and they are linked and have a significant impact on the preservation of the supports.

Temperature expresses the speed with which atoms and molecules that make up the matter move. If it is high, it indicates a higher average kinetic energy of the molecules, because there are more collisions between them [13]. Instead, *relative humidity* (RH) can be defined as the ratio (in percentage) between the vapor pressure in a humid air sample and the vapor pressure saturation at the same temperature [5, 7]. Both parameters directly influence each other. Chacón and González [14] recommend that stable temperature and relative humidity conditions should be maintained at average levels, according to the different documents located in the archive in spite of different documentary supports coexisting in the same physical space. Consequently, stable and controlled temperature and humidity levels must be established, in order to guarantee the durability of the different documents, so that the following recommendations could be followed:

Some guidelines for the preservation and conservation of medical documents would determine the selection of an average for the parameters of temperature and relative humidity, to allow preserving the different types and documentary supports that could be found in a clinical history:

- The lower the temperature and relative humidity of the room, the longer the paper objects capacity to retain their appearance and physical resistance.
- An average temperature between 16 and 20 °C and a relative humidity between 40% and 60% are recommended.
- These measurements must be permanently monitored through measuring instruments such as thermometers to measure the environmental temperature and hygrometers that measure air humidity.
- It is recommended to have instruments that control these environmental variables. For example, temperature can be controlled with the use of air conditioners and for humidity to have air dehumidifiers.

Table 40.2 Agreements on preventive conservation

	Temperature		Relative humidity	
Type of documentary support	Minimum, °C	Maximum, °C	Minimum, %	Maximum, %
Paper	15	20	45	60
Photography: black and white	15	20	40	50
Color photography	>10		25	35
Recordings	10	18	40	50
Magnetic media	14	18	40	50
Optical disks	16	20	35	45
Microfilm	17	20	30	40

Suggested temperature and relative humidity parameters [14]

High relative humidity affects all components of photographs by damaging the gelatin binder. Low relative humidity (RH) causes the binder to shrink. High temperature plus humidity combined with pollution fades colors, yellow paper. This is especially true for acidic paper. This combination also contributes to growth of molds which cause permanent damage.

Fluctuations in temperature and humidity are also damaging. Roosa [11] suggests RH between 30% and 50% without cycling more than ±5% a day. Negative films deteriorate further at 40–50% RH. Storage temperature should be as low as possible (18 °C for B&W prints on polyester film base: for cellulose acetate, even colder or freezing temperatures). Freezers need to be vapor-proof. Low temperatures and low RH are ideal (Table 40.2).

40.5.1.2 Lighting

Light is another aspect that accelerates the natural aging of paper and other documentary media, so it must be taken into consideration for its preservation [5]. Light is energy and energy is required for chemical reactions to occur in the paper and other supports. All wavelengths of light—visible, infrared, and ultraviolet (UV)—promote the chemical decomposition of organic materials through oxidation [7]. Light, especially sunlight, accelerates the deterioration of paper documents, acting as a catalyst in their oxidation; it causes the medium and inks to pale or change color (discolor, turn yellow, or darken) and leads to the weakening and friability of fibers of cellulose. Additionally, light can be a source of heat and as such of temperature elevation.

IFLA recommends the following levels of light: for reading and consulting rooms, it is acceptable between 200 and 300 lux and in storage areas between 50 and 200 lux [7].

Some guidelines for document preservation and conservation in this area could be the following:

- The use of natural and artificial light in equal parts in working (staff) and general public areas.
- In document deposits, only artificial light is recommended, with the lights off when they are not being consulted.
- The most suitable artificial light is 20 W light bulbs, which is warm, emits infrared radiation, and produces less light flow; however, the most advisable and economical is the cold light, if used with neutralizing filters. If it were not possible to suppress the entry of natural light, the use of filters, curtains, or blinds is recommended.

40.5.1.3 Air Pollution

According to Díaz and Gámez [5] and IFLA [7], air pollution refers to the harmful agents found in the air, which are gases produced by day-to-day activities (such as the burning of fuels) and large particles of different materials (described as dust); these damage documents and create reactions that compromise their status and durability over time. Gaseous pollutants, especially sulfur dioxide, nitrogen oxides, peroxides, and ozone, catalyze harmful chemical reactions that lead to acid formation in the documents, which accelerates the process of paper discoloration, wear, and appearance of spots. Environmental pollution and airborne particles (dust) represent two of the most harmful alteration factors for documentary goods.

Some guidelines for preservation and conservation in this matter could be the following:

- The archival rooms should be well ventilated, with a good clean air renewal. To achieve this, it is recommended to consider placing mechanical ventilation systems and corroborate that the air source is clean.
- The deposit areas' ventilation system must be independent of the areas used by clinical documents' users.
- Documents' accumulation promotes the concentration of dust. To reduce this problem, all doors and windows must be secured [15].
- To reduce dust, it is recommended to install air purifiers and leave it on 24-h a day to ensure air purification, both inside the archives and in the work and customer service areas. Also, make the filter changes when indicated.
- A routine and continuous cleaning plan must be maintained with care and supervision, both in the areas of document conservation and in the areas of staff work and general users.

40.5.2 Biological Factors

40.5.2.1 Microorganisms

Documents are mainly of organic origin and therefore vulnerable to be damaged by microorganisms [5]. These microorganisms are bacteria and fungi, which excrete enzymes that decompose organic materials into small products. Relative humidity is a factor that contributes to the proliferation both in the air and on the object where they are growing. Maintaining adequate levels of temperature and humidity in archival and work places is required [14]. If microorganisms that have destroyed part of the document support are found, a specialized company should be hired to install a vacuum chamber where the documents can be fumigated and then cleaned for residues.

40.5.2.2 Insects

Insects feed on organic substances such as paper, paste, rubber, gelatin glue, leather, and book fabrics [7]. They are silent destroyers and usually cause irreversible damage to paper. The large document predators are insects belonging to the order Blattodea (cockroaches), Isoptera (termites), Coleoptera (beetles), and Lepisma saccharina (silverfish, of the order Zygentoma), which are present under appropriate environmental conditions [14]. The values of temperature and relative humidity for the development of these insects are in presented in Table 40.3.

Some guidelines for preservation and conservation in this matter could be the following:

- The archival documents must be inspected permanently, verifying their conservation conditions in order to rule out the presence of insects.
- The temperature and humidity of the physical spaces of the archives should be monitored and kept under control, so that insects do not reproduce.
- If insects are found, specialized fumigation is required.
- A permanent and periodic fumigation program should be carried out.

40.5.2.3 Rodents and Birds

Rodents are responsible for the loss of a large number of important collections, as they gnaw paper, cardboard, leather, skins, and adhesives from bindings to feed or build their nests [14]. Birds are usually found on the roof of buildings: they can get inside and their excrement damage documents and generate a suitable habitat for the

Table 40.3 Biological agents and the suggested temperature and relative humidity to reduce infestation [14]

Type of insect	Temperature, °C	Relative humidity, %
Cockroach	25–30	<70
Silver fish	16–24	90
Termites	26–30	97–100
Some types of beetles	20–28	70–90

appearance of microorganisms. To prevent damage by rodents and birds, a permanent monitoring should be carry out on the building and on the documents. Measures against insects, rodents, and birds focus on sporadic fumigation and cleaning of physical spaces and roofs. It is recommended to maintain a pest control company to handle such fumigations, as well as disinfection of documents that may, in many cases, be considered contaminated or destroyed by some type of animal.

40.5.3 Natural or Human-Made Catastrophes

40.5.3.1 Floods

Water damage is usually potentially more damaging than that caused by fire. Provision should be made for possible breakdowns of water pipes as well as leaks. It is also important the maintenance of air-conditioning connections.

When designing a building for archives, or when adapting a space for this purpose, it is recommended to install pipes as far as possible from document and work spaces. When restauring old premises, it is convenient to redistribute old pipes into a safer location. In the same way, great care must be taken in the distribution of service spaces, such as bathrooms or dining rooms, as well as drinking water dispensers, so that they are far from the storage spaces, and with all the necessary mechanisms to avoid floods, such as drains and floor's tilt. Permanent monitoring of roofs and cleaning of rainwater pipelines should be carried out in order to prevent leaks and drain accumulations of waste that could result in roof damage and flooding.

It is recommended that the spaces destined to the archives are not located in basements, due to the filtrations that could be generated from the walls and the high level of humidity that these spaces normally present in buildings.

40.5.3.2 Fire

The protection against fire starts with the architectural design of the building health institution and its archive, which should provide for open spaces, emergency exits, adequate doors, and barriers against fire. The materials used in the building and equipment must be nonflammable and nontoxic or harmful to users and employees. In turn, fire detection devices and/or alarms must be installed, and their maintenance checked regularly. In all the archive areas, portable devices (fire extinguishers) should be placed to extinct fires exclusively with dry chemical powder, since it is not advisable, under any circumstance, to use or install water sprinklers, specifically in archives' areas.

40.5.4 Chemical Factors

According to Jaimes and García [16], chemical factors can be internal and external. Internal chemical factors are those originating from the support itself (the materials used in its manufacture), which with the passage of time affect the document. In many cases, the inadequate selection and use of the products used in the production of the paper, or other type of support, generates changes of coloration, to the whole document/photograph or in the areas near the written text or the registered information, until total loss of the material caused by reduction in flexibility, fragility, and fragmentation of the support.

External chemical factors are those produced by clips, hooks, and staples, commonly used to group or hold documents, and generally made of metallic materials and can rust to produce irreversible stains on the substrate [12], especially under unsuitable environmental conditions, affecting the good condition of the document. At higher humidity, there is a greater chance for rusting and damaging documents. Other potentially damaging materials are adhesive tape and glues.

40.5.5 Other External Factors

Documents can be damaged by incorrect manipulation by both staff and users: folds, tears, stains, and perforations [17]. In addition, handling of certain types of support should be done far from magnets and magnetic fields.

From the point of view of conservation, it is recommended that institutions elaborate and transmit guidelines for handling documents. Personnel that work should be trained to handle the documents properly, both during their processing and in their loan.

40.6 Other Documentary Supports Used in Medical Files

As mentioned, most of the documents that can be found in the medical files are written paper, photographs, slides, X-rays, and other electronic and digital documents.

40.6.1 Photographs and Slides

The difficulties caused by the preservation requirements of photographic documents, as well as a variety of their formats, have generated the creation of independent collections, separating them from the rest of the medical record.

In the past 50 years, the archival sector is paying greater attention to photographic documents especially to their preservation and conservation over time. They have been included as part of the audiovisual documents together with records, tapes, cinematographic films, videotapes, and prints.

In the past decades, most photographs are printed and are the final result of a development in the laboratory, through a process of positive, that is, obtaining generally positive copies on paper. There are also negatives in cellulose, cellulose acetate, and/or plastic and nowadays in digital format (depending on the production time of the original photo).

In many health institutions, photographs are found within medical record (MR) or as part of photographic archives linked to the MR file. A *photographic archive* is the ordered set of materials related to photography: positive, negative, glass, transparencies, slides, etc., produced or received by natural or legal persons, depending on their activities, and arranged in such a way as to facilitate their storage, preservation, and consultation [2].

Photographs should be properly stored in specialized furniture or enclosures. The material from which these furniture and cases are made should be noncombustible and not liberate harmful chemical gases. Glass plates are particularly fragile. Photographs should not be left loose in drawers or boxes. It is advisable to maintain them in folders, cardboards, albums, or envelopes. It is recommended that the photographs be protected or separated from each other, so that they do not stick together. If placed on a cardstock, select the correct type of glue to avoid material degradation. The cards must be larger than the photograph, so identifications or descriptions of the document can be placed outside the photo. If you use albums, these should be to install small photographs.

In the case of the negatives used to make a photograph, they are commonly made in glass, paper, or cellulose acetate, on which an image has been printed by photographic-light effects, revealed through chemical processes. This type of material can be installed in special envelopes, cardboard boxes, and/or albums.

For its part, the slides considered as photographic transparencies printed on a transparent support that can be projected on a screen by light can be installed for conservation, in envelopes that need to be acid-free. Slide albums should not be made neither of polivynil chloride (PVC) nor of colored paper. Paper and plastic envelopes should meet ISO standards.

Humidity and temperature are the main factors of deterioration of photographs and slides, but also chemical residues used in the photographic process can damage them. According to Santander [18], in order to guarantee photographic preservation, it is essential to have a strict control of the photographic process, since depending on the quality with which the development is carried out, the fixing and the different washes, it is going to guarantee that the preservation time of the different photographic materials is increased.

Poor manipulation by users and staff that manage and organize photographs and slides can also degenerate the documentary material, as do excessive light and temperature increase.

Finally, furniture without ventilation can also cause deterioration of the photographs. For a better preservation of these documents, it is recommended to separate the black and white photographs from the colored ones, as well as the negatives and slides, installing them preferably in metallic cabinets designed with ventilation systems.

Regarding the environmental conditions to conserve this type of documents, an average temperature of 15 ° C and a relative humidity of 40% are recommended. Photographic materials are sensitive to changes in temperature and humidity, so they must be placed in dry deposits [11, 18].

40.6.2 Electronic-Digital Documents

The "International Council on Archives" in its publication *Access to Information preservation, issues: ICA CITRA* [17, 19] points out that there are few studies on the preservation and conservation of digital information.

In many health establishments, as in various organizations in the world, the storing of electronic documents is done on hard drives or through the contracting of storage services in the cloud. Currently, document management systems allow large quantities of electronic documents to be stored, either directly produced in that format or scanned and digitized from paper/physical to digital, being the documentary repositories the mean to access these documents easily and safely. Despite this new way of handling digital documents, documents in optical disks are still generated and stored in health institutions.

The National Media Lab has established that the lifetime of optical disks oscillates between 5 and 100 years, until deformations, cracks, and holes, as well as bad manipulation, cause scratches that do not allow adequate reading [17].

Temperature and humidity also affect the conservation of these disks; temperature of 23 °C and 50% relative humidity are recommended for proper preservation. For this type of support, it is important to take action in case of variations of these elements. Storage units should not be located in places exposed to sunlight or in high temperature and humid environments.

Despite the conservation and preservation measures, it is important to keep in mind that all support systems get obsolete. It is important to apply ISO 13008 [20] on processes of migration and conversion of electronic documents. Optical disks should be maintained using special materials and liquids to keep the optics clean.

40.7 Guidelines for Cleaning Furniture and Documents in Files in Health Institutions

The following guidelines are presented regarding the cleaning of furniture and records of health institutions [21, 22]:

40.7.1 General Guidelines

- The cleaning of documents, filing equipment, and physical filing spaces in health institutions must be done routinely, systematically, and permanently, according to a schedule designed between the coordination of the file and the cleaning staff, with the aim of:
  - Permanently keeping documents, shelves, furniture, equipment, and spaces dust-free
  - Guaranteeing healthy working conditions to the staff
  - Keeping documents as part of the institution's documentary heritage
- Documentary cleaning is not done in the same way as an office is cleaned, since it requires knowledge, training, and special cleaning equipment, in order to avoid damage in documents' preservation.
- The cleaning plan must specify the periodicity of the activity, the materials to be used, and the way documents have to be treated, which is always under the supervision a specialized personnel.
- The personnel responsible for cleaning the furniture and documents must be adequately protected with long-sleeved gowns, dust masks, lenses, caps, and gloves, as well as other materials required to clean the documents.

- Solvents or volatile substances must not be used in the cleaning process.
- The cleaning of documents must be done in a specially conditioned place for this work, since, if it is carried out in the archival or office spaces, it could generate illnesses to the personnel.
- Vacuum cleaners should not be used on materials and documents that have magnetic devices. These should be cleaned with dry rags, dusters, or brushes. The vacuum assigned for such work should only be used in the cleaning of documents and for no reason will be used to clean carpets or chairs.
- An employee of the unit or archive department who knows the organization of the documents to be handled should be responsible for giving instructions to the person who will perform the cleaning, as well as frequently supervise their work, in order to verify that their work is carried out properly, filling the respective control format for special cleaning activities of documents and files.

Cleaning of shelves

- The cleaning staff must remove the folders and/or boxes from the shelf in manageable lots, depending on their thickness. In case of boxes of documents, it should be made one at a time.
- The folders and/or boxes should be placed on a conveyor car, in the same order as they were on the shelf.
- Once the documents and/or boxes have been disassembled, the rack will be cleaned with a cloth moistened with disinfectant cleaner and water, well squeezed, starting with the first upper section and continuing until the last lower section.
- After cleaning the shelf or tray, you should wait for it to dry, to install the documents again in the same order they were initially.

Cleaning of documents

- Before placing the boxes and/or folders in the section again, respecting their initial location, the documents are cleaned as follows:

The folder or box should be cleaned on a table away from the shelf or row of shelves that are being cleaned.

If the folders are located inside archive boxes, the folders in the box should be removed in an orderly manner, so that they can be integrated again in the same way they were installed.

After the folders are removed from the box, the box should be vacuumed, in all its parts, lifting the compartments in order to extract the stored powder in the best possible way.

Each folder should be vacuumed both externally and internally, always in one direction only.

Once the folders have been vacuumed, they will be placed inside the box and this one in the respective shelf, in the same order in which they were found.

If a fragile, friable, or broken material is identified, it should not be vacuumed, and the coordinating personnel of the unit's cleaning activity should be notified immediately.

When the material warrants it, replace the vacuum cleaner with a brush, fluff, or duster.

40.8 Conclusions

Photographic material needs to be preserved because it is part of our heritage. Some collections represent real treasures, the lifetime work of past specialists or of the entire medical departments. They maintain a highly educational value; their digitalization will simplify preservation and access to collections of images. Furthermore, the adequate digitalization and organization of these collections of images will be fundamental in the development of future AI diagnostic algorithms.

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Part VIII

Deep Learning and Blurred Vision

Deep Learning Performance for Triage and Diagnosis

41

Álvaro Iglesias-Puzas and Pablo Boixeda

Contents

41.1 Introduction

The clinical practice of dermatology is changing all around us. Emerging technological advances and growth in the size of medical information have led to increasing computer competence across a range of fields [1]. Digital imaging has become essential for documenting diseases, following patients and assessing treatment efficacy [2]. Algorithms support clinicians in the decision-making process as a response to the increasing need to standardize care and to assist midlevel providers to diagnose and care for patients [3]. However, point of care still heavily relies on the subjective and qualitative interpretation of clinical and diagnostic imaging findings [4]. Modern medicine is faced with the challenge of direct learning from all biological data necessary to solve complex clinical problems [5, 6]. As a promising interpreter of massive information, cognitive computing systems may be able to identify associations and trends that would not otherwise be noticed while shedding light to the increasing rate of the subjectivity of procedure and time costs [7–9].

Machine learning is a broad branch of computer science involving methods that enable machines to make predictions and learn automatically from experience [4, 10]. It encompasses from the simplest linear regression or decision tree models to modern deep neuronal networks where the model parameters can number in the range of millions [1].

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41.2 Deep Learning and Artificial Neural Networks

Recent advances in algorithms, computational power and access to massive datasets have enabled *artificial neural networks* (ANN) as the leading artificial intelligence method [11]. Inspired by biological neural networks in animal brain, ANN are based on connected units ("neurons") that perform parallel computations for data processing and knowledge representation [6]. Different from traditional *machine learning* approaches, they allow the integration of multiple layers that are not programmed by human input. Thus, the model is fed with raw data and develops its own representations for pattern recognition without defining feature detection [1, 11, 12].

An ANN is configured for a specific application, such as pattern recognition, through a learning process. Supervised learning approaches generate a function that reproduces output by inferring from a collection data with attached diagnosis, whereas in unsupervised learning, the model trains itself on data [13]. Once training is completed, connections between the nodes of different layers work cooperatively to create an association between features that best correlate to a diagnosis [4, 14].

41.2.1 Convolutional Neural Networks

Almost all *deep learning* models, e.g. *convolutional neural networks* (CNNs), have shown the most promising performance for image classification tasks. Conventional CNNs combine multiple layers of representative learning with deep architecture (Fig. 41.1). Convolved layers obtain local weighted sums (*feature maps*) at every layer by computing filters (*kernels*). This operation consists in the multiplication of local neighbours of a given pixel by a small array of learned parameters that travels over the given image (Fig. 41.2) [13]. Pooling layers reduce the size of the feature map by keeping the maximum or the average step size (Fig. 41.3) [4, 9]. As data flows through the layers of the system, these convolutional and pooling layers are repeated several times, while the input is progressively transformed into a more complex and abstract representation [4, 12, 13]. Finally, a fully connected layer that performs the classification of the overall image makes the last layer [1].

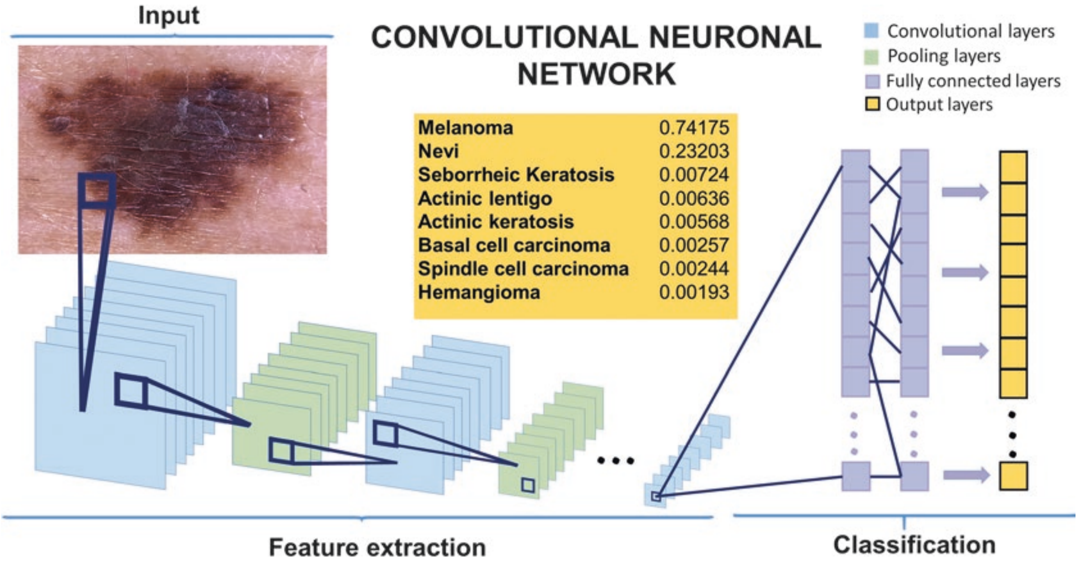


Fig. 41.1 Schematic overview of a CCN architecture. CNN take input images and transform them using convolution and pooling operations. Finally, a fully connected layer performs the classification of the overall image. Based on: Iglesias-Puzas Á, Boixeda P. Deep Learning and Mathematical Models in Dermatology. Actas Dermosifiliogr. Published online 2020. https://doi.org/10.1016/j.ad.2019.01.014

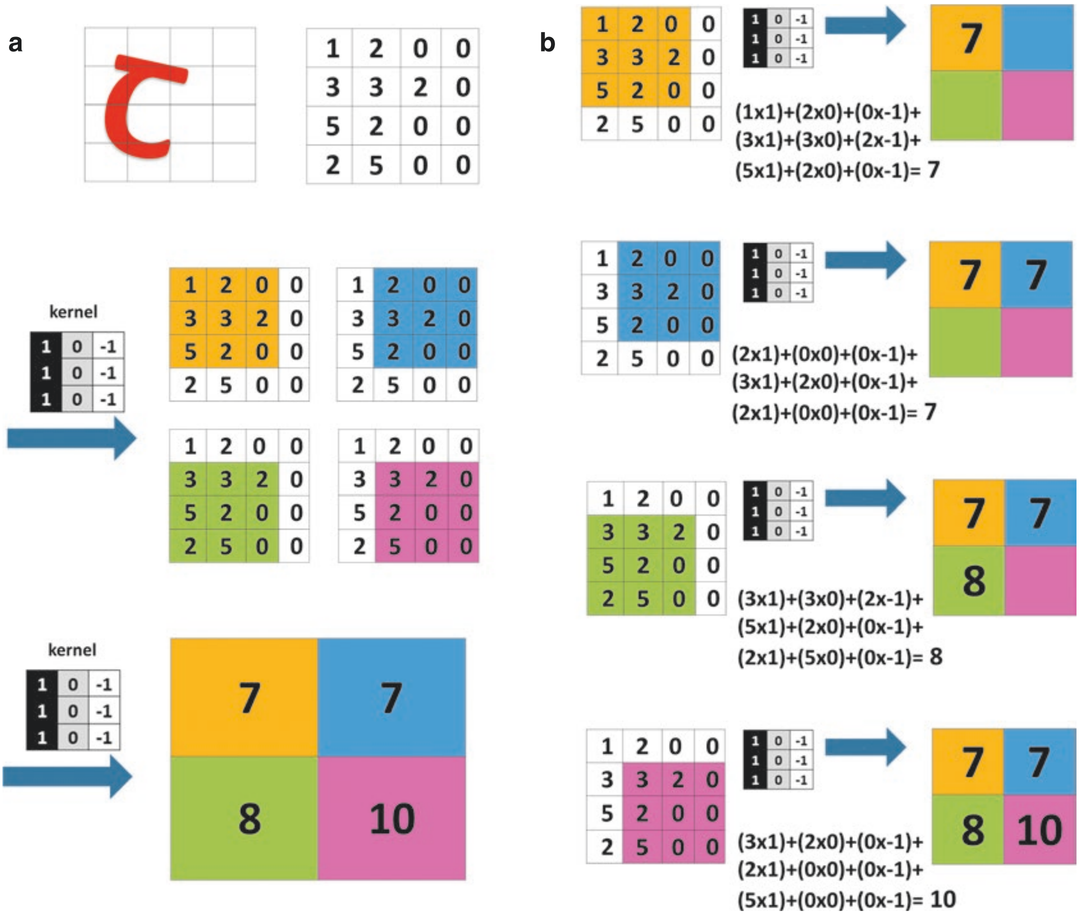
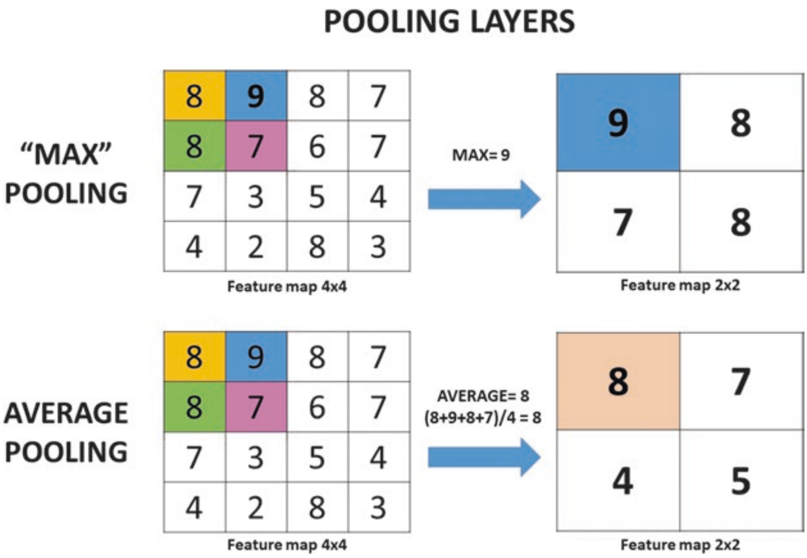


Fig. 41.2 Convolution method. (**a**) The input, which is represented by numbers, is multiplied by a convolutional kernel. (**b**) An example of convolution operation

Fig. 41.3 In the pooling layer, the results of convolution are summarized by computing a max or an average



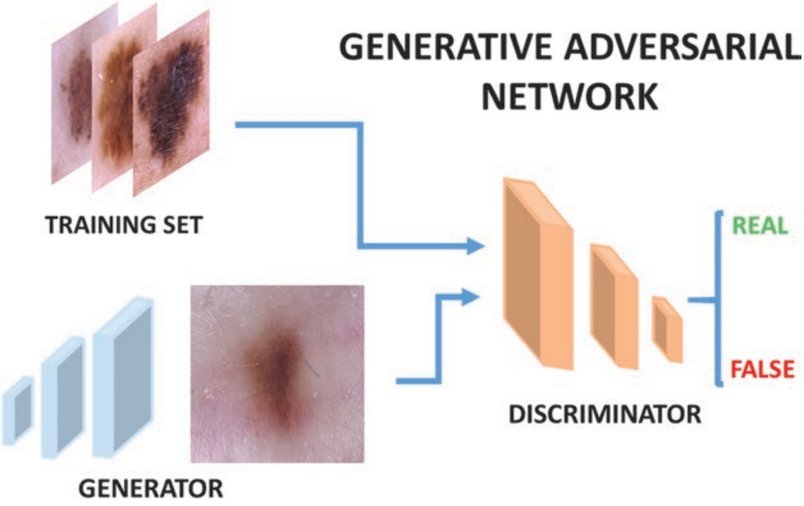


Fig. 41.4 Architecture of a proposed GAN

41.2.2 Generative Adversarial Networks and Quantum Computers

Computational methods were introduced to eliminate the subjectivity and increase sensitivity and specificity in skin image diagnosis.

Goodfellow proposed in 2014 a new method to study digital images that is called *generative adversarial networks* (GAN). GAN represent a powerful tool for classical *machine learning*: a generator tries to create statistics for data that mimics those of a true data set, while a discriminator tries to discriminate between the true and fake data. This process of learning with a generator and discriminator is like an adversarial game and finish when the discriminator is unable to discriminate between the true and the generated data. GAN can generate pictures of imaginary celebrities by studying real ones. Therefore, it is a *machine learning* idea that uses the rivalry between the two neural networks. Both networks are trained on the same data set. The first one, known as the generator, is charged with producing artificial outputs, such as photos or handwriting, that are as realistic as possible. The second, known as the discriminator, tries to discriminate between the true and fake data. Based on those results, the generator adjusts its parameters for creating new images. This process of learning with a generator and discriminator is like an adversarial game, and finish when the discriminator is unable to discriminate between the true and the generated data. The goal of the discriminator is to maximize the probability of assigning the correct label. Thus, the discriminator and generator are adversaries in a machine learning game (Fig. 41.4) [15].

This has led to practical applications such as generating photorealistic images and videos, image super resolution and image inpainting. This has resulted in significant interest in industries such as driverless cars, finance, medicine and cybersecurity. GAN can generate, for instance, pictures of imaginary celebrities by studying real ones.

GAN have been successfully used for image synthesis tasks for generating benchmarking data and cross-modality synthesis. Thus, the generator is optimized based on the interaction with the discriminator. This process is known as adversarial training, where the generator tries to minimize the loss between the generated images and the ground truth, while the discriminator tries to detect the fake generated data [16, 17].

The automatic diagnosis procedure, performed either on dermoscopic or on conventional images, follows these key steps:

1. Image pre-processing (applying filters to remove noise and artefacts)
2. Lesion segmentation and contour extraction
3. Texture, colour and contour analysis on the delimited lesion area

4. Relevant (colour, texture, geometric) descriptors' identification
5. Classification

One of the most important steps is the lesion identification and segmentation because the correctness of this step affects the next diagnosis phases. An artificial intelligence method for pigmented and non-pigmented lesion segmentation has been developed using generative adversarial neural networks. The network was trained and tested on a large set of images acquired with smartphone cameras. The results showed that approximately 92% of the lesions are correctly identified on the test set [18].

Recently, several authors proposed generative adversarial networks for skin lesion synthesis. GAN generate realistic synthetic skin lesion images to address the lack of annotated data, which is expensive and requires much effort from specialists and for classification [17, 19].

Skin lesion restoration is an essential preprocessing step for lesion enhancements for accurate automated analysis and diagnosis. Digital hair removal is a non-invasive method for image enhancement by solving the hair-occlusion artefact in previously captured images. A realistic hair simulator for skin lesion images using conditional generative adversarial network has been proposed [20].

41.2.2.1 Quantum Generative Adversarial Networks

Ordinary computers use bits, where one is represented by either a one or zero. A quantum computer uses qubits. *Qubits* are the fundaments to quantum computing and are equivalent to bits in ordinary computers. *Qubits* can be in a 1 or 0 quantum state, and also they can be in a superposition of the 1 and 0 states. These computers are still too noisy and far from widespread use although some are already available [21, 22].

Quantum generative adversarial networks is a tool for classical machine learning where a generator and discriminator are equipped with quantum information processors. Data is either of quantum states or of classical data. They can exhibit an exponential advantage over classical adversarial networks [22].

41.3 Applications of Artificial Intelligence to Imaging and Diagnosis

The CNN and their proposal of multilayered perception have revolutionized the concept of pattern detection in medical imaging. Their applications align strongly with computer vision for detection and classification of images into diagnostic categories [1].

The dermoscopy technique, developed to improve the diagnostic accuracy of naked-eye examination, has now become an important routine in clinical practice [23–25]. However, and despite special training in different dermoscopic algorithms, dermatologists only rarely achieve test sensitivities greater than 80% in the clinical assessment of melanocytic lesions [26]. Therefore, there has been considerable interest in developing computer-aided systems for melanoma diagnosis in order to provide a high and widely reproducible diagnostic accuracy [10, 24].

Landmark publications have demonstrated the use of CNN to classify images of melanoma [26]. Esteva et al. trained a CNN on 129,450 clinical and dermoscopic images of 2032 different diseases for two critical binary classifications: keratinocyte carcinoma vs benign seborrheic keratosis and malignant melanoma vs benign nevi. Their image classifier demonstrated higher sensitivity and specificity when compared to the average performance of 21 board-certified dermatologists [4, 23, 27].

Subsequent publications have been an emerging trend in dermatology. Marchetti et al. and Haenssle et al. reported their computer vision systems classified melanoma dermoscopy images with an accuracy that exceed of most of dermatologists in their studies [24, 28]. The potential of artificial intelligence to outperform dermatologists of all levels of knowledge is now a known reality. In recent years, efforts are focusing on confirming the reliance on *deep learning* for guiding clinical decisions in a real clinical setting.

Although automatic diagnostic techniques have been introduced for the early diagnosis of skin cancer, the feature extraction capacity of deep learning enables its application in a wide range of fields [8]. Recently, they have been used for onychomycosis diagnosis. Seog Han et al. achieved a diagnostic accuracy, using a CNN trained with 49,567 images, that was superior to that of most of the dermatologists who participated in their study [29]. With respect to inflammatory diseases, there have been efforts to developing new tools for the evaluation of psoriasis based on clinical images. Psoriasis Area Severity Index (PASI) has significant limitations in term of subjectivity and inter-observer variability, which complicates efforts to measure effective treatments in clinical trials. Artificial intelligence algorithms now could help to bring objectivity and precision to traditional metrics for evaluating the severity of psoriasis [30]. Computer vision and *deep learning* could also assist with syndrome classification. DeepGestalt, a community-driven phenotyping platform trained on tens of thousands of patient images, outperformed clinicians in three initial experiments: two with the goal of distinguishing subject with a target syndrome from other syndromes, and one of separating different genetic subtypes in Noonan syndrome [31].

Deep learning is progressing rapidly, and its application range extends in other medical specialities such as radiology, pathology, ophthalmology and cardiology [1, 4].

41.4 Artificial Intelligence for Melanoma Diagnosis

41.4.1 Screening and Decision Support

Cutting-edge imaging technology is improving the way we detect melanoma. Sequential digital dermoscopy imaging, artificial intelligence, total-body 3D photography and mobile health applications have added capability to traditional clinical skin examinations [5].

Despite these advances in dermatological imaging, the ideal positioning of artificial intelligence remains an unanswered question. If considered as a triage tool, digital image-based machine learning models present a promising means of extending the reach of dermatologist to meet the growing need for skin cancer screening [10]. The utilization of *machine learning* in the clinical setting by non-specialists may facilitate the early detection of melanoma and prioritize patients with the highest risk of cancer [28, 32]. However, the output of machine learning classifiers tends to be generated as a probability score of various diagnoses, which may include small probabilities of malignancy for clearly benign lesions [1, 32]. An inadequate interpretation of results could increase the number of unnecessary or inappropriate referrals. Dermatologists should shed light on this challenging problem by defining thresholds for probability of malignance [32].

In a real-life clinical setting, dermatologists may consult with decision-support systems for confirming or refuting their own primary judgement. These models may be of assistance in the reduction of unnecessary excisions, thus lowering the number of benign excised lesions per melanoma [33]. In addition, for people with multiple dysplastic nevi, melanoma accuracy relies on the experience and skill of the evaluating clinician. Changing lesions could be flagged automatically by artificial intelligence systems integrated into whole body imaging systems [34]. However, if lesion management is replaced (instead of complemented) by *machine learning* decision, the dermatologist could be likely to excise the lesion to exclude the low, but nonetheless significant, possibility of melanoma [33].

Downloadable mobile applications could also change the way we diagnose and monitor skin cancer. They emerge as a natural way to deliver these *deep learning* algorithms beyond reminding and coaching people to perform self-skin examination [32]. Symptom tracking apps for electronic devices may capture dermoscopic images for review and monitoring of any suspicious lesions, which could revolutionize traditional teledermatology and improve the patient involvement in disease management [35]. Dermatologists should be aware of these emerging tools in order to counsel their patients appropriately.

41.4.2 Advantages and Drawbacks

A digital automated skin diagnosis offers many advantages, including consistent interpretation and high sensitivity and specificity [8, 36]. Although sensitivity may not be 100%, automated diagnoses may decrease the risk of overlooking a melanoma in clinical practice. Furthermore, computer-assisted automated diagnosis could make possible physicians to play an active role in the early diagnosis of melanoma, particularly by reducing late diagnosis and improving the survival rates [37].

Precision medicine-based revolution in medicine requires the more objective analytic tools that allow stratification of patients into smaller and more personalized groups [4]. Cognitive computing may be able to reduce medical errors and minimize ineffective treatments or adverse events, providing the right treatment to the right patient in a quantitative manner [7, 11]. Artificial intelligence could decrease the work burden, so that physicians could spend more time with their patients, resulting in improved patient care and satisfaction [7].

On the other hand, a number of limitations exist with the integration of cognitive computer into clinical care. Currently, *machine learning* tools cannot match human intelligence and life experience as they capture insights implicit in data, but rarely reveal casual connections, preventive or management advice [38, 39]. Since a neural network is not able to determine which factors it used to arrive at a diagnosis (*black box problem*), artificial intelligence recommendations must always be evaluated by a physician [7].

Another key limitation of algorithm performance is the lack of clinical information. In a real-world clinical setting, an encounter with the actual patient provides more information than that provided by using just the image at hand [12, 23]. Artificial intelligence is not a substitute for the ability of the physician to integrate data with physical examination and generate differential diagnosis as it seldom takes into account the possibility of multiple pathologies or pathologies that augment the presentation of the other [1, 38].

Dichotomous classifications of algorithms could only determine whether a melanocytic lesion is benign/malignant and should or not be excised [33, 40]. For these binary decision tasks, it is necessary to establish an operational value that if exceeded causes the input image to be classified as a melanoma [23]. Moreover, these clearly endpoints rarely consider overlapping features in borderline melanocytic lesions or the possibility of a “third way” such as short-term follow-up examination [24]. No machine can supply the human touch, the empathy that a physician conveys in a trusting doctor relationship, or substitute the final decisions when it comes to diagnosis and treatment [38, 40].

CNN become more accurate as the data volume gets larger. Thus, its usefulness in the diagnosis of rare diseases with insufficient datasets has not been fully established [29, 41].

Concern arises in how well artificial intelligence will perform in diagnosing atypical melanomas, a group of lesions where computer aid diagnosis would be most useful. Efforts need to be made to ensure the inclusion of adequate numbers of challenging lesions into training datasets [34].

Large amounts of data with labels, clinical photographs, are not standardized in terms of image composition. Furthermore, with increasing image acquisition, the need for a storage system with ordered and universally available information while remaining confidential has emerged. *Blockchain* technology, which is used for cryptocurrency and *Bitcoin*®, offers a secure network with image ownership and location encoded as transactions [2, 3].

Additional considerations for deep learning models include the absence of effective regulatory standards for diagnostic software platforms and medical errors that arise from use of these applications [4]. Although artificial intelligence-provided diagnosis could be superior to that of a dermatologist, lack of validation and no legal precedents of these algorithms limit the application until clinical trials as well as longitudinal and practical experience are available [3, 14].

41.5 Conclusions

Machine learning will revolutionize the standard of care in dermatology. In the near future, computers will inevitably replace some human workplace activities, while patients benefit from the diagnostic speed and accuracy provided by the algorithms [38]. However, for an artificial intelligence to be functional, dermatologists should establish wherever the emerging technologies are employed in routine diagnosis. As clinicians, we must embrace this change with enthusiasm and learn to integrate it into our patient care paradigms [3, 14].

Conflict of Interests The authors declare that there is no conflict of interest.

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42

Ophthalmic Images of Blur and Blurred Ophthalmic Images: Fuzzy Pictures in Scientific Practice

Jordi Cat

Contents

42.1 Introduction

Here is a familiar experience: we look into the distance at something that moves towards us and catches our attention, but we cannot identify it with certainty; this is partly because we cannot identify its visible features such as its shape and contour. When it gets closer, after a while, we focus our attention and we begin to identify sharp contours and a defined shape, a human body, and then a pattern of other shapes that make up a face, some clearly others not, and yet we can identify the person's gender and much more. We use other words for the same cognitive task, some with a negative connotation of difference and separation, to distinguish, to differentiate, to tell apart, to make out, or to discriminate others a more positive connotation of similarity and aggregation—to recognize or to categorize. Around the image of that body, now sharper, well defined, the environment appears fuzzy and literally out of focus. We can try also to take a picture of the approaching person, and while we see the contour of our phone screen sharply, the image of the person appears blurred. These are all examples of blurred vision and blurred images.

Looking at the sky, similar daytime experiences involve the features of distant birds, or close birds we cannot identity more specifi-

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cally, or the contours of clouds, or, at night, the sighting of planets and stars. Depending on how we understand their spatial features, we use an idealized conception to draw more "realistic" images that remove any fuzziness, for instance, in the geometric shape of the bird's head or wings, or the Moon. We adopt the same idealized image to judge our blurred experience defective. Alternatively, we can draw a "realistic" picture truer to the fuzzier visual appearances.

When we draw a landscape we often choose intentionally to render smaller or leave out features and details of things we locate at farther distances; by certain standards of realism or accuracy, the picture is misleading; yet, that's how someone else will recognize the distance and find the picture informative. We get similar effects in photographs. By contrast, it is when we draw a schematic cloud with a sharp geometric contour depicting a certain shape, someone else will recognize the kind of thing we're portraying, but at the level of the spatial features, size aside, they will be right to declare the picture too sharp and inaccurate.

Elsewhere [1] I have presented the problem behind such kinds of experiences and representations—some more concrete, some more abstract, many connected—as a cognitive problem, namely, a problem of categorization, call it a matter of cognitive uncertainty or of vagueness; the latter is more often associated with the use of a word for the category, independently of what we think a category is. In my account, the problem is best understood along dimensions characterized by the failure of strict dualities such as precise/imprecise, sharp/fuzzy, image/picture, subjective/objective, and prescriptive/descriptive. They do not fit in any one-sided way so that only one term applies. The relevance of fuzziness is both descriptive and practical, scientific and artistic, and phenomenological and theoretical. Relevant categories for empirical and theoretical purposes might not be easy to apply sharply, with epistemic certainty and objective ontological or theoretical commitment—that is, to what something is "really" like. Fuzzy characteristic of images, from my standpoint, are in that sense particular cases even though present specific issues of their own. The standard of sharpness as an absolute ideal or a limited is also normative in the sense that we often assume that maximum sharpness or precision is the right standard. This has methodological and practical implications guiding epistemic and technical decisions. It is, for instance, an underlying assumption of systems of classification and the theoretical and practical values of their application—that is, choosing among a limited set of labels and descriptions. Yet, I have drawn attention to the fact that empirical and normative judgments of fuzziness or perceptual blur are relative to particular standards, and the introduction and adoption of those standards are contextual. This relativity explains also the complexity of ordinary and scientific practices of connective categorization—we often represent them as inferences, in other cases they are genetic relations tracking causal relations or empirical correlations in data clusters as in online recommendations or predictions for consumer choices. The relativity explains why for a given categorization at a more phenomenological level (I call it intrinsic content) can be linked to other categorizations (I call it extrinsic content) through all sorts of contingent and contextual rules (I call them IC-EC rules) and extend thereby to beliefs and decisions in which they play a part—we act on the recognition of a certain empirical quality such as smell and its extrinsic description as dangerous. Similarly, fuzzy categorizations are compatible with extrinsic, connected sharper ones. Blurred images might still allow to identify features, and vice versa, phenomenologically sharp images might prompt a challenge for additional, possibly more abstract and general forms of categorization. Medical diagnostic taxonomy fits this situation (see below). Moreover, representations of fuzziness, even of visual blur, might not appear fuzzy or blurred to us, yet they "are" blurred relative to some intended content or target of representation, for instance, a circle is a blur image of a point (more below).

I have noted also that limitations on descriptive sharpness are not only facts of our ordinary and scientific cognition and practices but also have their use and value. We find benefit in blur, ambiguities, and grey areas as both cognitive cues and practical opportunities—whether in the cognitive cues indicating distance or motion, of in protection of someone's identity or privacy, or in the more abstract flexibility in the application of the law. As in the selective nature of scientific modeling, also the cognitive and practical value of many representations requires an optimal, not maximal, level of detail and precision. The same applies to the more basic visual features of pictures.

While by the mid-nineteenth century the ideal of scientific research had established itself around specific ideals such as unity–simplicity and sistematicity–, objectivity and precision, actual scientific practice has frequently succeeded only by falling short of adopting or meeting them. In the sciences fuzziness is a pervasive feature and concern, qualitative and quantitative. Sharpness – high definition or precision – is in practice relative, as is accuracy, and its use and significance, even in the use of measurement results, are a practical and contextual matter. In the case of pictures, imaging technologies have enabled the use of stable visual records with information and capabilities beyond those in individual real-time observations. Those pictures are relevant to research and clinical purposes of understanding and intervening, and as result, fuzziness in those pictures acquires the same significance. In the aftermath of the invention of photography, sophisticated critics insisted in identifying the ideal of sharpness with scientific, rather than artistic, standards and purposes [2]. But it is not a simple matter, as more concrete and phenomenological categories are used to guide the application of others, as is the case in classification and diagnosis. A set of visual categories for visible symptoms help identify some explanatory factor or a more informative or practical feature. These are just instances of application of different, connected categories.

In psychology, for instance, an active area of research is the study of facial recognition and in particular the use of facial features as indicators in order to identify personality traits such as trustworthiness. Fuzzy-simulated facial images help illustrate how babies perceive low spatial frequency information when drawn to faces and suggest the visual salience of darker "blobs" in eye areas ([3]: p. 96); they also help from a methodological standpoint, for instance, in the simulation of noise-distorted images of faces to help design data-driven physiognomic experiments to tests recognition biases ([3]: p. 107).

Think also of the content of typical blurred images in pictures of frequent use in astronomy, processed telescopic images with visible and invisible radiation, oncology, mostly internal imaging pictures, or dermatology, external visible-light photography. In the history of astronomy, fuzziness in observations and photographic records have typically been considered an optical challenge relative to sharper features associated with a standard model of the target systems; this has led to numerous optical developments. But in other cases, distributions of matter—dust or gas—do not support such models and render the fuzzy pictures unexpectedly accurate. A recent celebrated telescopic photograph of the M87 black hole (Messier 87) was effectively produced by means of sophisticated uses of computational forms of aggregation of data involving intensive image digital processing. The bright disk surrounded the dark area is manifestly fuzzy, without any theoretical model or empirical supporting a sharper alternative. And yet it manifests the degree of circularity that allows researchers to claim the image as evidence in support of Einstein's general theory of relativity. The circularity is visualized in some analyses with an embedded sharper ring diagram. A century earlier, the astronomer Max Wolf and his colleagues used wide-field photography to map out the fuzzy distribution of brightness in the night sky and use the information to quantify stellar distribution. Blurred pictures were also accepted as depictions of the motion of celestial luminous objects.[1]

Some dermatological pictures record the distinctive lack of sharp boundaries in the pattern of skin marks that is characteristic of conditions

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[1] I am grateful to Scott Walter for this historical example. On the M87 photograph as a superposition of increasingly sharp photographs of photon rings, see M.D. Johnson et al. Universal interferometric signatures of a black hole's photon ring. Sci. Adv. 2020;6: eaaz1310. I am grateful to Peter Galison for drawing my attention to the article.

such as actinic keratosis on the scalp. The fuzziness at the visible level directly serves the purpose of sharper classification for an informative diagnosis (Fig. 42.1). In other cases, the failure to issue a reliable and precise diagnostic—that is, to apply category precisely and reliably—may risk the misidentification of a malignant cancer and a serious threat to the patient's health (Fig. 42.2). In others, diagnosis and treatment require addressing the visible fuzziness, not the one at the level of pathological classification: the absence of well-defined visible boundaries requires superimposing marks with simpler and more precise boundaries in order to determine useful information about shape and size (Fig. 42.3). The added visible marks, on the actual area of skin and on photographs, may provide also guidance and restriction in the application of a particular kind of intervention, whether a surgical removal or a local chemical or laser treatment.

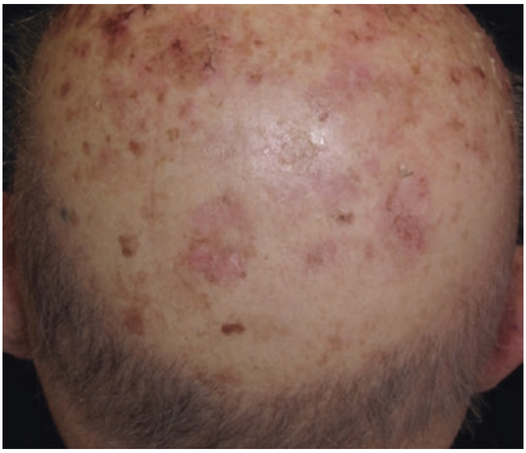


Fig. 42.1 Photograph of a case of actinic keratosis (courtesy of Paola Pasquali)

In the earlier book and other works, I have focused on the scientific attempts to represent fuzziness and use the standard to pursue methodological and practical goals. In particular I have discussed mathematical forms of indeterminacy in formal and practical situations of problem-solving and focused on the formulation and application of fuzzy-set theory, with the introduction, testing, and application of, for instance, causal models and digital imaging. One distinctive aspect to the conception of fuzziness, I emphasize, is their explicit acknowledgment of prototype-relativity, contextuality, and, more surprisingly, subjectivity. In this study I turn to the conceptualization, exploration, instrumentalization, and management of blur in ophthalmic sciences, especially vision optics.

Below, I will discuss how the project of engaging blur is embedded in a constellation of different mathematical and pictorial tools, with different standards and purposes, investigative and clinical, often inseparable. An expression of this is the various kinds of pictures of blurred vision, many of which do appear blurred, and

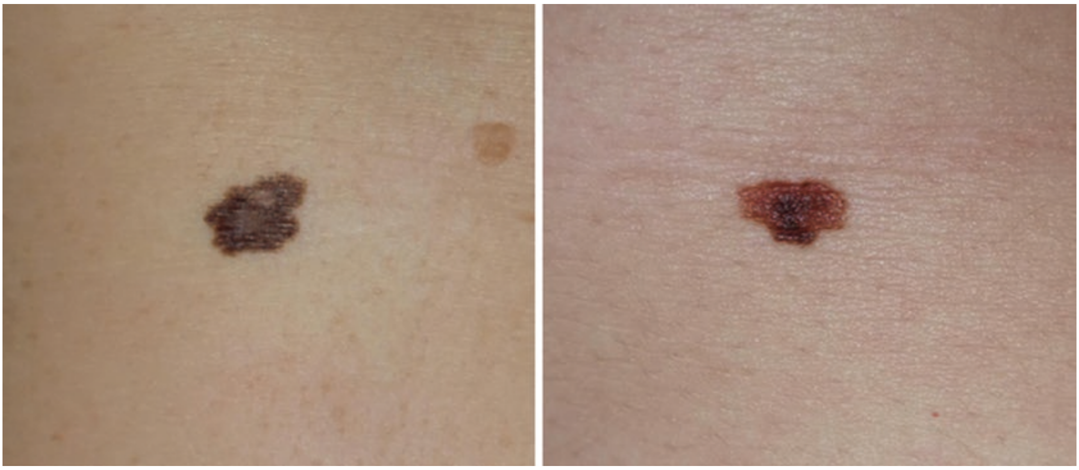


Fig. 42.2 Photograph of a case of malignant melanoma (left) and a benign compound nevus (right) (courtesy of Paola Pasquali)

Fig. 42.3 Photograph of a case of spilus nevus (courtesy of Paola Pasquali)

their different and shifting roles and uses. Different kinds of images include hand drawings, analogical and digital photographs, and computer visualizations. I will show how, historically, they have been introduced in an ongoing project of simulation that begins with so-called artificial models, artificial visual aberrations, and photographic simulations and experiments. Computer simulations followed suit, each with their one specific condition. I will also show how the different kinds of pictures, like the roles and goals they serve, do not always arise to replace others but instead develop different relations to others and introduce new uses. In the new pictorial regime, research and clinical practice rely on a combination of drawings, different kinds of photographs, and computer visualizations. The simulations and the pictures, I will show, play a number of roles: providing illustration and classification, prediction, potential explanations (a deeper level of classification), exploration, testing, evidence for or against explanatory hypotheses, evidence for or against the effectiveness of research tests and techniques, evidence for or against the reliability of diagnostic tests, and the effectiveness of corrective treatments and tracking the evolution of conditions and treatments.

My analysis will contradict and supplement a number of accounts of the significance of images in terms of their content and use. An issue I will focus on, more salient than in the application of mathematics of fuzzy-set theory, is how the central interest in the phenomenon of blur in visual experience prompts pervasive and endemic considerations of subjectivity and objectivity. Different relations and tensions between standards of subjectivity and objectivity play a key role in the evolution of research and clinical intervention. This aspect finds expression in the interpretation, production, and use of pictures.

42.2 Subjectivity

Neither fuzziness nor subjectivity can be eliminated from visual (and mathematical) representation. Sharpness has been long held up in the sciences as a normative standard, not just a descriptive notion. But the choice and application of the different standards are also contextual and practical; and in optometry and ophthalmology, its prescriptive function is predominantly clinical and not theoretical or pictorial. From this old and widespread medical practice comes the familiar negative conception of blur applied to vision and to image quality. It is a notion fundamentally conceptualized as error, relative to a geometrical standard, and it serves inseparable descriptive, explanatory and clinical purposes.

The auxiliary value of blur in ophthalmic pictures is twofold: serving clinical and methodological goals through its descriptive, evidentiary and predictive value. Unlike other fuzzy images, the ones displayed in optometric pictures and described in reports of blurred vision form the basis for precise diagnostic categorization, either through optical models or clinical procedures of subjective refraction—“which is clearer, 1 or 2?”, “can you read the letters in the bottom row?”—even of objective refraction. By contrast, anatomical fuzzy pictures are not interpreted as defective or representing a defect, except when external technical sources of fuzziness are identified, and precise graphic boundaries may be introduced for the sake of communication or practical guidance in clinical intervention. I will argue that photographic depictions of blurred vision and other kinds of images inform and guide enduring lines of research and treatment of vision, central to which is a subjective/objective dichotomy.

While interest in photography arose as part of other, widespread scientific, artistic, and popular interests, in the sciences it lined up with new commitments. Thus, in the mid-nineteenth century, scientific photography entered the history of pictorial objectivity: a preference for standardized, homogenized, socialized, collectivized, working objects (also mass-manufactured consumer goods). It can be considered a reaction to the particularity, complexity, or unavailability of natural specimens or phenomena that are the intended target of general and intelligible scientific representation. Sometimes the working images played, and still do, a role that is more than illustrative of categories or theories, a role of an exemplary visual standard for fixing the distinctive identity of a phenomenon or entity, guiding the general application of the corresponding category, coordinating the training and practice of researches and clinicians, and even constituting the endpoint of inquiry ([4]: p. 22).

The historians Lorraine Daston and Peter Galison, in particular, have traced the evolution of pictorial practices and standards of presentation and representation. They have focused on three codes of epistemic virtue: truth to nature, mechanical objectivity, and trained judgment ([4]: p. 18). According to them, the sequence of their respective rise and dominance is a process of mutual reconfiguration and reassessment rather than elimination and substitution.

Truth to nature was the ideal of knowledge handmade illustrations. They showed a reasoned image of a type, not of a particular specimen, that a genius illustrator intuited through selective, idealizing synthesis. It was allegedly the artist’s self that made possible the visual depiction of universal types out of a diversity of observed, flawed actual particular individuals, resulting in the non-naturalistic visualization of kinds, types, or classes through drawn figures of individual ideal archetypes that are unrealized in the empirical world. Idealization led to truth about the general level of reality involving the typical, the normal, and the ideal. The images were, then, working objects of science, or natural philosophy, associated with its proper object of knowledge, the truth about nature. The process of creation was artistically continuous with the shift toward a more naturalistic standard of drawing from nature.

The same shifts in standards apply to machine drawings, which—though unmentioned by Daston and Galison—meant to portray generic technological designs or patterns rather than unique instruments and often included generic naturalistic landscapes. Of interest are also blueprints for machines and instruments and their parts, which, with diverse and shifting conventions, have long played the instrumental role of standards for construction [5, 6].

Much artistic drawing and machine drawing are instances of a systematic application of elementary geometrical figures. This has, for centuries, been the more general application of geometrical models to schematic drawing. Such drawings included a selective or idealized depiction of spatial structures assumed to be central or essential to understanding certain material entities or phenomena of interest. In fact, with Euclid’s *Elements*, geometry became the paradigm of knowledge and reasoning. Like technical machine drawing and mapping, geometrical optics and geometrical models of vision are examples of this perspective on the spatial world.

We find, for instance, geometrical laws of vision and graphic simulation of viewpoints representing the effect of foreshortening of objects along a line of sight with distance as a visual cue (geometry of projections): Greek triangles of vision in, for instance, Euclid's *Optics* (ca. 300 BC) were replaced by triangles in the pyramid of perspective in the subsequent, Renaissance formulation. In Leon Battista Alberti's *On Painting* (1435), the use of perspective reversed the graphic focus of the viewpoint, centered on the vanishing point on a horizon. The geometry of cones or pyramids of projection is indifferent to the difference in understanding of the behavior of light in relation of the eye—whether emitted or received by the eye.

Daston and Galison point to the late eighteenth-century philosophical tradition of idealism articulated by the philosopher Immanuel Kant. This marked a shift in epistemic and methodological standards in the early nineteenth century from truth to nature to mechanical objectivity. For Kant two kinds of mental representations restricted the application of reason to the world of experience: (1) objectively valid representations in relation to all possible objects of experience but independent of any particular sensations, externally oriented, making up the natural world of objects of knowledge; and (2) subjective particular representation of the sensibility, internally oriented, the domain of the self.

Mechanical objectivity was exhibited in atlases of mechanical images produced by workers through automatic physico-chemical transfers. Measurement instruments and techniques were developed in the same spirit. Not only did objective images provide representation beyond human capabilities; in the ideal observer, the self was an epistemic obstacle to reliable representation; and to counter it, the new ideal of objectivity of the early nineteenth century relied on an ethos of self-restraint. From this non-interventionist stance, the mechanical image was distinctively free from emotion, will, judgment, and interpretation, modeled after machine performance and mechanical mass manufacturing and reproduction in the new machine age.

The resulting appearance was naturalistic, that is, closely resembling the target visible cases, and its paradigmatic form was—although perspectival and invisibly judgment-led—photographic depiction, a representation not of general truth but of a diversity of particulars with much incidental detail. The image provided a density of truth at different scales limited only by the film's grain size and resulting resolution. The techniques established a link between automation and authenticity, but often at the expense of visual precision, accuracy, detail, or verisimilitude. In addition, the trustworthiness of the resulting image and its evidentiary value in support or rejection of a hypothesis stemmed from the elimination of any subjective contamination. Yet, besides the personal viewpoint and the technical choices involved, many early photographs were continuous with artistic works, since they imitated artistic compositions, with their corresponding conventions and singularities (more on the relation to art in Sect. 42.4) [2, 7].

Photographic illustration and evidence established a medium for a new kind of empirical (visual) access to particular things or phenomena and the kinds of things they instantiated. They also created a community of viewers as virtual witnesses by coordinating the possibility of shared, similar/same subjective experiences. Their use implied the representation of an objective version over and above any of them and suggesting the existence of a counterpart also over and above all of the particular subjectivities and experiences.

The same ethos of detached pictorial depiction supported the introduction of self-recording graphic instruments visualizing precise measurement and of symbolic graphs visualizing mathematical functions and their application to empirical relations.

Throughout the second half of the nineteenth century, the scientific study of perception itself resulted in the proliferation of material models of sensory physiology and the challenge of finding physio-anatomical and psychophysical invariants. They suggested a needed for alternatives to supplement or replace the problematic mechanical production of objective images. According to Daston and Galison, the first was structural objectivity. This was the objectivity of logical and mathematical relations without reproduction of private sensations. It took the form of symbolic expression, with at most a diagrammatic, geometrical visualization of relations ([4]: Chap. 8). The second was trained judgment: subjectivity reappears fixing the revealed content of the mechanical image now interpreted by an expert through pattern recognition ([4]: Chap. 6).

Finally, the authors point to a more recent kind of image produced by computer simulations: no visual representations of visible particulars, but engineered, technological visualizations, visual presentations of data and computations—with a controversial hybrid status I will discuss in Sect. 42.5, between the theoretical and experimental ([4]: Chap. 7). Images no longer simulate seeing but their own artificial, instrumental production and use. In the cases I consider, computer simulations do not replace drawings or photographs, only assign them new roles.

The purpose of this brief summary of their historical account of objectivity—with additional considerations of my own—is to help begin delineating distinctive features and uses of pictures of blurred vision. Just like the history of objectivity cannot be separated from the history of subjectivity, nor can the history of precision be separated from the history of imprecision, vagueness or fuzziness. My exploratory account of the presentation and representation of blurred vision examines how both dual pairs of concepts, objectivity/subjectivity, and precision/imprecision–fuzziness–are exemplified and connected and how their complex connections also show change, especially along conceptual, methodological, material, practical, and graphic dimensions.

The case of blurred vision, unlike the cases and changes Daston and Galison consider, kept the subjective phenomenon firmly in focus and methodological use, for theory and clinical intervention; in both their theoretical and clinical uses not subjective experience and the observer’s judgment play uneasily a central role as object of inquiry, practical intervention, and evidentiary gold standard (see below).

In general, pictures of blurred vision represent the corresponding class of perceptual phenomena through pictures of blurred images. As depictions of individual vision, of a viewing subject, they are then viewed by another viewing subject, with the difference that the she recognizes the blur as part of a larger field of view (extended in space or time) by contrast to the sharper images it also includes. In this way she can conclude that the blurr in the picture (of someone's blurred vision) she observes is not a systematic error of her own eyesight. But her view or image of the picture is still part of someone's visual field. Pictures of blurred vision, we can conclude, are unavoidably locked in a network of subjective experiences whose goal is to appreciate the distinctive blurred character of one such image and vision. Thus, subjective visual experience or subjective images were first recorded and reproduced in material working objects, that is, in an objectified, public form, sometimes known as subjective drawings. Photographs and computer simulations took the application of the material and mechanical objective standard further but only reconfigured, not eliminated, the significance of subjective drawings—and of subjective reports.

As I discus in more detail in the next section, beginning in the seventeenth century, optical-anatomical models of vision were introduced with growing explanatory power over different kinds of optical aberrations especially in connection to the design, use, and development of new optical instruments. The same models were adopted with the same theoretical and practical goals to explain and correct visual aberrations of the human eye.

By the mid-nineteenth century, preoccupation with the project of a naturalistic theory of empirical cognition, that is, beyond introspective philosophical psychology, had become common both in Britain and Germany. In the footsteps of optical models of vision, the project took the form of developing new objective, materialistic, quantitative, physical, anatomical, and physiological models, whether theoretical or material, and of subjective sensations and appearances, including color sensations. Part of it, besides phenomena of color and binocular vision, was Fechner and other psychophysicists seeking systematic general relations between stimuli and sensations across individual differences. Throughout the first half of the nineteenth century, this project became informed by the added challenge—and methodological benefit—of separating out accurate perception of external objects from optical illusions [2, 8].

This preoccupation with the multiply problematic nature of sensations was typically placed under the comprehensive rubric of subjectivity. And, as a result, it would set at the heart of this scientific project the philosophical subjective-objective polarity, and its corresponding English and German idioms in originals and translations. In Germany, for instance, the physicist and physiologist Hermann von Helmholtz's *Handbuch der physiologischen Optik* [9], and its English translation, *Treatise on Physiological* Optics [10], took stock of the contrast between, on the one hand, objective light rays and objective intensity of color differences and, for instance, on the other, subjective sensations without corresponding external objects, subjective colors, subjective brightness, and subjective similarities.

In Britain, in the footsteps of Thomas Young, David Brewster, John Herschel, George Wilson and Helmholtz himself, James Clerk Maxwell declared that color research concerned compound sensations that were "the object of consciousness" ([11]: p. 120) in a search for general laws "identical for all ordinary eyes" ([11]: p. 130) that could be "objects of thought" ([11]: p. 119); and this was a combined matter of geometry, physics, physiology, and laws of sensations ([12]: pp. 411 and 418). A decade later, he would add that all vision was color vision, since even the recognition of shapes was the outcome of noticing differences of color, including differences in their brightness ([13]: p. 267). But the nature of sensations, which involved "subjective impressions of colour" ([14]: p. 393), had methodological implications; it made the evidence a personal matter, to be derived from consciousness ([13]: p. 267).

As a result, he stated [13]:

> The science of colour must therefore be regarded as essentially a mental science. It differs from the greater part of what is called mental science in the large use which it makes of the physical sciences, and in particular of optics and anatomy. But it gives evidence that it is a mental science by the numerous illustrations which it furnishes of various operations of the mind. (p. 268)

Maxwell credited Helmholtz with leading the effort to resist the standpoint of "the purely subjective school of psychologists" and its methodological doctrine that since "a sensation can exist nowhere except in our own consciousness, the only possible method for the study of sensations must be the unbiased contemplation of our own frame of mind" ([15]: pp. 595–96). This he called the "method of self-contemplation" ([15]: ibid.). Instead, Helmholtz and others treated "a fact of consciousness as if it were an electric current" ([15]: ibid.). The best results he found in a literal standard of psycho-physical research, which applied this physical approach to investigating the correlation of varying physical stimuli and resulting sensations ([15]: ibid.).

Maxwell also noted that it was in the application of optical methods in, for instance, precision electromagnetic measurements that the distinction objective and subjective methods appeared: "Some German writers distinguish this method of using the mirror and scale with a lamp as the *objective* method, the method in which the observer looks through the telescope being called the *subjective* method" ([16]: p. 515, original italics). The consideration extends to the emblematic status of photographic records: "The objective method is the only one adapted for the photographic registration of the readings" ([16]: ibid.). It is in this spirit that he remarked on a more speculative psychological and spiritual level that science "strips off, one after another, the more or less gross materialisations by which we endeavour to form an objective image of the soul" ([17]: p. 760). Here, at the boundaries of its expanding empire, science stood for the emblematic production of the objective image.

As I discuss in the next two sections, the standard was applied also to blurred vision. Unlike color, blur was not conceptualized as an intrinsic or relational property of objects, but a distinctively visual phenomenon, a condition of the eye and mind. Throughout the nineteenth century, prior to the advent of photography, the only visual record was, as for the case of color, the personal hand-drawn reproduction of subjective sensations and its mechanical reproduction in print. In 1869 the German physicist Wilhelm von

Bezold demanded an objective representation of blurred vision [18]. Three decades later, the French eye doctor François Ostwalt lamented to his fellow participants in the International Congress of Ophthalmology that he had only a subjective demonstration of the advantages of meniscus lenses (periscopic lenses), and they "were missing absolutely every objective demonstration" ([19]: p. 350, my translation).

Yet, neither the subjective/objective duality, the subject matter of blurred vision, the subjective kind of hand-drawn picture nor its methodological use have disappeared from research in vision optics. In recent times, testing of predictive and explanatory hypotheses about visual aberration and image quality still look to matches between so-called "objective and subjective patterns" and, for working objects, to so-called "subjective drawings," that is, of now called "subjective images" [20].

The optical models for both explanation and correction of vision by lenses featured since the seventeenth century a central hypothesis shared by natural philosophers, doctors, and opticians alike that vision was the exercise of the refractive power of the eye (more in the next section). To assess that power remains the key procedure, in any of its multiple and changing techniques, to explain and correct individual eyesight conditions and minimize, for instance, any kind of experience of blur. The methodology still includes techniques labeled as subjective. Already at the turn of the twentieth century, the American doctor J.E. Littlefield opened his manual for practicing the new science of optometry with this definition of the discipline: "The employment of subjective and objective mechanical means to determine the accommodation and refractive states of the eye and the scope of its functions in general or the act of adapting glasses to the eye by using such skilled means as will determine their choice" ([21]: p. 7).

The subjective-objective distinction included a predominantly practical and procedural interpretation: "the methods of diagnosis may be either objective or subjective; either an examination of the eye itself on the part of the operator or a questioning of the patient as to the objects seen by him under the various conditions arranged by the operator (p. 159). Objective tests included ophthalmology, retinoscopy and ophthalmometry, and the subjective ones included trial lenses and test cards. More surprising, however, is the psychological background notions Littlefield included, perhaps following similar ideas in Helmholtz, in the presentation of perception in general. They were meant as part of the theory of cognition that includes the optometry student's task of concentration and self-improvement and especially her future work on clinical correction: 'Man is of a dual nature (he has two minds.) The objective or conscious mind; the subjective of unconscious mind.' (p. 8) And the task of concentration, for instance, 'deals directly with the objective mind, which is ever on the alert to sensation'" (ibid.). Healing, however, may involve suggestive treatment that requires the stimulation, though communication, of the "subjective mind of the sick person" (p. 184).

More modern manuals and research presentations have kept the phenomenological distinctions regarding the nature of images and their quality—either optical or subjective—but have dropped the psychological models of clinical situations:

> *Subjective refraction* is the term applied to the technique of comparing one lens against the other, using changes in vision as the criterion, to arrive at the dioptric lens combination that results in maximum visual acuity ([22]: p. 790).

Now, where lies the subjectivity? The public determination of acuity level is set exclusively by test subject according to her private perceptual experience, that is, which, from this perspective, only she can access and whose report only she can ascertain and warrant: "the conclusion of maximum acuity depends on the judgment and the opinion of the human subject tested" and thus "the examiner's determination must rely exclusively on subjective reports of perceived differences" (ibid.). As the epistemic authority on this matter, the subject cannot be wrong about her experience, her "subjective judgment" ([23]: p. 76), and it is this alone, a "subjective interpretation" ([22]: p. 823) that in this case fixes the acuity level that the examiner will declare.

This subjective quality sets the general distinction between subjective and objective methods: “In subjective techniques, the patient makes a judgement of the correct focus. In the objective methods, the clinician or an instrument makes a judgement of the correct focus” ([23]: p. 67).

The theoretical and practical dimensions of psychophysics have survived around an irreducible subjective-objective polar axis, in the form of studying associations “between physical external stimuli and subjective human perception” ([24]: p. 163). The theoretical and practical challenge still have the form of integrating psychophysics, even its modern replacement, with objective approaches such as optics, optometry, ophthalmology, and neurobiology (p. 164). In the next section. I point to the application to the subjective phenomenon of blur of those mathematical, physical, and anatomical and physiological models. The basic purpose, for instance, is to provide an objective quantitative measurement of the “subjective quality of perception” and the patient’s own “subjective evaluation” (pp. 248 and 250).

What is the worry? The connection between the subject and the examiner, which enables the latter’s access, diagnostic report, and corrective treatment, relies on linguistic communication. But this also depends on the patient’s subjective interpretation of the terms or signs used in the verbal exchange. As a result, clinicians worry that the exchange that communicates the information describing the personal experience is limited by the semantic uncertainty of meaning, of categorization, and, in addition, by the possibility of error applying the relevant categories: “One cause of error in determining the subjective findings is that genuine communication may not exist between the examiner and the patient” ([22]: p. 858). That is, while “the terms have specific meaning to the examiner, to the patient, “better” or “worse” may be interpreted as referring to brightness, contrast, squareness of the acuity chart, or tilt of optotypes on the chart” ([22]: ibid.). In this rich sense, optometry theory and clinical manuals identify the subjectivity of the perceptual phenomenon in question, and the techniques for its exploration are expressed in “a patient’s subjective responses” (p. 869, [25]: pp. 197–98).

As I will note, in educational and research settings, the role of subjective judgment has been often supplemented with a graphic rendering of the individual’s retinal experience; in such representations, the depicted image stands for the relevant kind of visual experience.

The distinction between subjective and objective extends from the source of authority and the method of access to the explanatory models of individual processing of visual information. For instance, in the case of lens accommodation involving the control of the relevant muscles to alter focus and eliminate or reduce the image blur, the objective physiological system (neuropathways) may respond to objective optical variations in focus that the subjective perceptual system fails to identify, that is, it is “unmindful of the sensation and accompanying process” ([26]: p. 928).

Still, the objectivity of objective refraction procedures is not free from the action or judgment of human operators. Retinoscopy by direct inspection of the eye provides only independent confirmation of subjective results. And in objective photorefraction methods, for instance, light is recorded and analyzed after it has illuminated, and macula is reflected back out by the retina. But the resulting photograph or video of pupils require interpretation by operators or clinicians ([27]: pp. 685–86). Eliminating the patient’s subjective judgment is only a step toward fully automated objectivity: “When the judgment of a human operator is replaced by the logic of an instrument, a computer, or both and when the endpoint is reached by action of the instrument or computer, the objective refraction has been automated” (p. 682).

Only mechanical experimental techniques, material explanations, and mathematical representation stood for the opportunity to get an objective handle on the elusive subjectivity of ghostly blurred experiences. In the second half of the nineteenth century, Bezold lamented the challenges posed by physiological experiment and mathematical deductions from optical theory and was eager to represent the essence of the blurred images objectively with the help of a lens ([18]: p. 282).

Still today, the pursuit of automation, or mechanical objectivity, aims to replace the subjective methods. The enforcement of different methodological standards serves the same practical, clinical endpoint. Yet, it doesn't mean that the objective result is a faithful representation of the other, the subjective judgment, or that it is its equivalent replacement. While they may be correlated, they do not often match. On the one hand, objective methods often present systematic biases. On the other, optical correction may introduce spatial distortions that the patient interprets as blur, while a judgment of sharp vision might not correspond to a reduction in the size of the blur circle. Background conditions and perceptual habits matter. The use of subjective judgment to validate objective results and methods is not strictly reliable, then, since the comparison involves results that are not strictly comparable: "It is incorrect to strictly compare results of retinoscopy and the subjective refraction and conclude that one is right or wrong. The two tests are actually not measuring the same thing" ([27]: p. 710). I will show below (see Sects. 42.4 and 42.5) that the dominant practical goal is the procedural objectivity of clinical methods, applicable to human population at large, leaving out a role for individual subjective judgment. But its successful pursuit of such a project relies on research whose target and methods depend on individual subjective content and input. This explains that a variety of standards, kinds, and uses of images of blur is both relevant and unavoidable.

42.3 Representing Blur: Terminology, Modeling, Measurement, Explanation, and Correction

42.3.1 Fixing Blur in the Study of Vision: Early Practices, Experiences, Concepts, Words, and Pictures

The phenomenon of blur has long been a recognized fuzziness or variance in the application of geometrical categories or features such as edges, shapes, and locations. They are features of illuminated regions in visual space corresponding to illuminated regions in object space, in which the target object offers an exposed surface whose points, according to some geometrical-optical model, constitute sources of light rays or waves.

As a representation of fuzziness in perceived images, the notion of blur is uniquely embedded in an evolving cluster of concepts or descriptions: qualitative and quantitative, within geometrical, optical, and anatomical-physiological models, with different purposes and different roles for photographic and computational representations or simulations. The uncertainty or vagueness of categorization has a rich, distinctive, and specific expression and significance in the optometric conception of blur.

During the first half of the seventeenth century, optical models of light's behavior through apertures and lenses of different shapes became established in the context of projects of natural philosophy concerned with light and cognition, often in relation to the demands of telescopic observations. For instance, astronomers and natural philosophers such as Galileo, Scheiner, Kepler, Descartes and Huygens adopted highly geometrical models in conjunction with simple anatomical models of the eye to suggest models of vision that could provide optical explanations and guidance for cases of visual function and malfunction [28].

After the systematizations of the early eighteenth century, especially from the hands of Newton and Smith, developments during the nineteenth century took place on different fronts: (1) mathematical models of light and optics, for instance, by Gauss, Fresnel, Foucault, and W. Hamilton; (2) anatomical-physiological models of vision, for instance, by Young, Listing, Helmholtz, and Maxwell; (3) instruments for exploration, for instance, by Helmholtz; and (4) measurement models of visual performance, for instance, by Snellen. These developments continued especially during the second half of the twentieth century, with more sophisticated modeling and measurement of optical aberrations and their sources on the eye, including the balances between aberrations of the cornea and the crystalline lens. The new mathematical models and measurement techniques had led by the late twentieth century to the rise of objective refraction and computational simulation [29].

Identifying blur as a theoretical and clinical target has been a sustained and driving goal in that history. The evolving constellation of conceptions of blur is embedded in an equally evolving cluster of connected geometrical and optical models with explanatory, predictive, and practical purposes. Also the optical and optometric idiom "blur," as is its interpretation, is embedded in an evolving vocabulary for the ground zero of visual vagueness. In the hands of natural philosophers, this vocabulary would enter philosophical discussion and receive the more abstract formulations that connected with the terms of the classical discussions in Greek philosophy of vagueness and precision in relation to conceptual boundaries. Also the Greek formulations were rooted in the ordinary perceptual habits of visual separation or distinction and the common practical use of blades with sharp edges to cutting out parts of things. On such grounds, images could represent ideas more abstractly, notably first in the context of the geometry of drawing lines, and the pursuit of thinking and true knowledge was introduced in terms of separation and boundaries: defining terms, analyzing ideas into their parts and cutting nature at its joints [1].

Even projects of rationalist philosophers such as Descartes and Spinoza were situated in a European culture that looked to the classical world of Greek philosophers and their systematic geometrical methods and to a new world of vision, with new optical instruments, problematic perception, and creative visual depiction—still after the standard of classical perspective [30]. For them too, ideas and images, seeing and thinking, regained their shared historical bond, and models of concepts and rational thinking—under the light of Reason—became metaphorically supported by optical and geometrical models of clear and distinct vision and geometrical boundaries.

It is only in the late nineteenth century that the old term "blur" entered the English optical and ophthalmological literatures from the ordinary usage for smears and stains that prevent vision. The doctor S.W. Morris, for instance, wrote of "confused images, or 'blurring'" ([31]: p. 236). Until then, the scientific and philosophical discourse of optics and vision was articulated around the central opposition distinct/indistinct (confused), applied to both vision and images. Two other oppositions follow, with more intuitive connotations, clear/unclear and sharp/unsharp. As new research in optics and vision was contributed in the nineteenth century also from German natural philosophers, mathematicians, astronomers, and doctors, their corresponding oppositions were *deutlich*/*undeutlich* and *sharf*/*unsharf*. The French used *distinct*/*indictinct* and *flou*. For related descriptions such as "dissipation" and "diffusion," Germans used *zerstreuung*.

In 1738, the British doctor and Newtonian mathematician James Jurin published an addendum to Robert Smith's influential *A Complete System of Opticks*, "Essay on Distinct and Indistinct Vision" [32] (between 1734 and 1742 Jurin sought to defend Newton from attacks mainly against his mathematical doctrines by the idealist philosopher George Berkeley, who had written also on the topic of vision). He was following Newton in the *Opticks* (1704), as well as Smith, and applied the categories distinct and indistinct, or confused, to vision, images, and pictures. And he linked them specifically to the perception of the optical features that Newton and others had adopted as fundamental geometric contours and colors. Jurin thus distinguished between perfect and distinct vision. It's an optical-geometrical distinction between perfectly distinct and imperfectly distinct vision in which in one case the image of a point-source is a point, whereas in the other the image is a "larger point." The first depends on the object's distance, the second depends also on its size. Still, in both cases, the object, he noted, is distinctly recognized ([32]: p. 116). In cases of indistinct vision, Jurin noted the uneven distribution of brightness resulting from the failure of the eye to focus the light from a point source on a point on the retina. He depicted it with a schematic geometrical model combining optics and anatomy in which he represented the blur circle and called it *circle of dissipation* (Fig. 42.4). The indistinctness is not in the precise lines but in the space around the center, defined relative to the point the area substitutes, represents, and delocalizes.

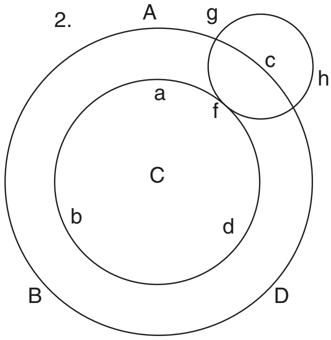


Fig. 42.4 Jurin's circle of dissipation (From Jurin (1738), "Essay on Distinct and Indistinct Vision," Fig. 2)

Also the natural philosopher and polymath Thomas Young adopted, in ground-breaking and influential essays, the idioms "indistinct" and, more occasionally, "confused" to characterize the failure of an image or perception to be perfect or distinct–for instance, in "Observations on Vision" [33], "On the Mechanism of the Eye" [34], and the chapter "On Vision," of his *A Course of Lectures on Natural Philosophy* ([35]: vol. 1, pp. 447–456). And, like Newton and Smith before him, Young applied the category diffused or diffusion, in the sense of spatial distribution, to the expansive state of light or a vapor (ether) over a surface. In Scotland, during the same period, David Brewster sought to explore vision and its illusions through the integration of geometry, optics, chemistry, crystallography, and anatomy in his *Optics* (1829). For quality of vision, he too adopted the idiom of distinctness.

In the Continent, the influence of books by, for instance, Listing, Donders, and Helmholtz paved the way for adopting an extended vocabulary of visual precision. Their English translations prompted a shift in the English vocabulary of optometry. The German mathematician Johann Benedict Listing wrote in *Beitrag zur physiologischen Optik* [36] equally of *scharf* (sharp) and *deutlich* (distinct) vision, boundaries, and images. To them he opposed *undeutlich* (indistinct) boundaries and images and the *Zerstreuung* (dispersion or diffusion) circle and field (ibid.). The Dutch physiologist and ophthalmologist Franciscus Cornelis Donders commissioned from his colleague Herman Snellen a standardized chart of symbols to measure visual capacity, which Snellen called *Probebuchstaben, zur Bestimmung der Sehschärfe* [37], translated into English as *Test-types for the Determination of the Acuteness of Vision*. In the work translated into English as *On Anomalies of Accommodation and Refraction of the Eye* (1864) [38], Donders adopted the terms "distinctness," "accuracy," "sharpness," and "acuteness," soon to be replaced by "acuity," to which he opposed "indistinct" (*undeutlich*) and "diffused" (*diffuse* and *zerstreuung*). The same German terminology was adopted by the physiologist and physicist Hermann Helmholtz in the monumental *Handbuch der Physiologischen Optik* (1867) [9]. The English translation, in 1924, of the third edition established in ophthalmological research and practice the English terms "blurred image," "blurred vision," and "blur circle" ([10]: vol. 1, part 1). Meanwhile, the terms "visual acuity" and "blurred vision" were introduced in North American optometry circles by J.E. Littlefield in his practical manual *Optometry* (1905) [21].

42.3.2 Optical Models of Sharpness and Blur

Geometrical-optical models of ideal vision set the earliest standards of objective and precise depiction, prediction, explanation. It is on such grounds that they can provide also clinical guidance regarding blurred vision. They consist in geometrical models of optics featuring points and straight lines that stand for light rays traveling along straight lines from target/object points diverted at an angle by refraction, rather than reflection, at the lens' surface and converging onto conjugate image points in perfect focus (location) on the optical axis of the lens. The study of the role of refraction is known as dioptrics. Perceived blur is, in such models, a condition of the phenomenological categorization of the field of view in terms of geometrical and brightness features. The aim of vision optics is to serve its explanatory and clinical aims by mapping such a condition onto optical features and measures of quality. For chromatic aberrations, color becomes another relevant feature. Here, however, I will restrict my discussion to monochromatic aberrations.

Three common idealizations in such models are the following: light following a ray path in the vacuum (or a constant uniform medium with a much lower density than the lenses it encounters); restriction to monochromatic light, with a single angle of refraction per ray determined by the medium; and small angles relative to the optical axis connecting the object and image point through the lens (paraxial, Gaussian optics).

The geometrical model can be extended to the more complex physical geometry of wave optics. Both basic models provide the basis for quantitative mathematical descriptions.

For the sake of explanation, the geometrical model provides a model of vision by identifying the eye as an optical system with dioptric properties. Different quantitative features of the eye's anatomy lead to models of different complexities. For instance, the model of vision may be complicated further by introducing more complex mathematical wave models of the physical behavior of light.

The standard of perfect sharpness in a perceived image is introduced relative to an eye model in which the pupil and the crystalline lens form the dioptric system that brings about the projection of images on the retina. In the simplest case, when the rays pass the plane corresponding, in a schematic geometric eye, to the eye's aperture, the focus places the image point corresponding to the object point on the plane corresponding to the retina. If the perceived object is represented as a set of points, each of which constitutes the source of a (reflected) light ray, the projected (perceived) sharp image is the set of corresponding points on the retina ([32]: Chap. 1, [39], Chaps. 1 and 2, [40]).

The refractive status of the eye is determined by the focal distance of the lens, in particular, the location of the focal point inside the eye conjugate to the object point at infinity, while the eye at rest, that is, with minimal accommodation at the lens so that its refractive properties are kept constant. When the cornea and lens bring incident parallel rays to focus on the retina, the eye is considered emmetropic.

Relative to such a standard, a number of aberrations are categorized as refractive errors and can be defined in this type of model equally in geometrical terms, based on the location of the (refractive) focus. The distance from the retina is a measure of so-called defocus. In the myopic eye, for instance, the focus falls in front of the retina. The eye projects sharper images only of near objects; the condition is popularly known as nearsightedness. In the hypermetropic eye, the focus falls behind the retina; the eye only projects sharper, clear images of distant objects; and the condition is popularly known as farsightedness. Historically, the dioptric model of vision can be traced back to work by the mathematicians and astronomers Francesco Maurolico, around the mid-sixteenth century, and, especially, Johannes Kepler, in the early seventeenth century, published in his *Dioptrice* (1611).

Another refractive aberration is astigmatism; it was identified first as an optical phenomenon by Newton and described and measured as an eye condition by Thomas Young in 1801 [34]. Two meridians of either the cornea or the lens, at 90°, present maximum and minimum curvatures. As a result, they introduce both a distortion and different focal points (whether both nearsighted or farsighted, or mixed). The resulting blur is caused then by the arrangement of multiple foci associated with meridians of different curvatures (the order of the blur circles and the intersection points of incident rays form a caustic curve along the optical axis, Sturm's conoid). Between the focal points set farthest apart lies the perceived blur circle known in some models as the circle of least confusion. These three refractive aberrations, myopia, hypermetropia, and astigmatism, were clearly distinguished and given an optical explanation by Cornelis Donders in 1864 [38]. What these and other conditions contribute to the experience of optical blur are different sizes, shapes, or distributions of brightness.

Another age-related hypermetropic condition—distinguished also by Cornelius Donders, and attributed to Kepler—results from the growing inability to accommodate the eye, a mechanism in normal vision established by Young at the turn of the nineteenth century. References to a neuromuscular mechanism of accommodation fall outside the purely geometrical model of optical behavior and integrate geometrical-optical and anatomical-physiological models. On the anatomically extended eye model, the sharpest image is projected on the small area of the retina called the fovea, a depression inside the macula, where the density of cone photoreceptor is highest.

We have then a geometrical concept of blur. On this geometrical model of the behavior of light, a blurred image is the result of the defocus that for each point of the object projects onto the retina a circle, the so-called blur circle, instead of the focal point. This geometrical model may still be complicated further, by noting not just the idealized multiplicity of point sources making up the target object, but the fact that, from the same geometrical standpoint, natural images are composed of points at different distances from the retina and therefore focused differentially.

This fact suggests a distinction between natural and artificial images: natural images present a statistically rich structure that can only be approximated by the artificial test images displayed on a flat digital monitor during psychophysical experiments and subjective refraction. Experimental results suggest that the role of contrast also becomes problematized, as in natural images contrast energy is distributed over a broad band of spatial frequencies in the structure [41].

The models can be enriched further. Extended mathematical models of the geometry of ray and wave optics contribute additional constellations of mathematical concepts for the representation of blur conditions such as blur circle size, point spread function, wavefront error, and a number of contrast and resolution measures. They constitute key standards of so-called aberrometry and are often categorized as metrics for image quality (see below).

42.3.3 Blur in Embodied Optics: Anatomical-Physiological Models

Within sufficiently rich optical and biological models, defocus blur may not be considered only an error, but a source of information, for instance, for biological and cognitive tasks of a human perceptual system (p. 1). For the actual processing and use of such cues for organ development or for establishing fixation or detecting distance or motion, the brain might use simpler empirical models. The information may concern also the target object of an imaging instrument. In the latter case, phase contrast imaging technology as in electron microscopy exploits optical information about different refractive indices of different structures in a sample system that resolves light into waves out of phase with one another. The model supports phase retrieval algorithms such as the Gerchberg-Saxton algorithm [39, 42].

Anatomical and physiological models, then, especially since Helmholtz's contributions [9], have long supplemented the different geometrical optical models. The integration narrowed the scope of the application and also extended the range of objective approaches and successfully contributing added explanatory, predictive, and clinical value. For predictive and clinical purposes, an important sort of empirical information that these models, and more complex optical ones, help provide is the relative magnitude or visual impact of additional effects. This can provide a helpful measure of their compensatory role in the explanation of visual processes and phenomena and of their potential masking role as confounders in testing situations.

A central model of this type targets the anatomical and optical structures that set effective limits to the maximum sharpness or minimum blur, at least relative to the geometrical ideal of optical focus. One constraint is the role of pupil size; for the same dioptric error and power of the eye, the diameter of the blur circle depends linearly on pupil diameter [39], since the effects of lower and higher-order aberrations (see below) show a direct dependence. In addition, diffraction-induced blur resulting from the interaction of light with, for instance, the contour of apertures such as the pupil becomes magnified as the pupil-dependent aberrations are reduced.

Another limiting factor involves cellular structures, the size of photoreceptors, and the density of their distribution. As a result, the image of a point object on the retina is not a point but a diffraction pattern, with a system of rings around the so-called Airy disk ([43]: p. 217). An additonal type of factor is neural, involving the density of neural pathways connected to the density of photoreceptors. Such limiting conditions set the effective standard of visual sharpness.

Another key set of neural models target the neuroanatomical process of accommodation. It is the mechanism that modifies the dioptric power of the crystalline lens in order to reduce the blur-inducing defocus on retinal images and keep them focused and sharp [44]. These models incorporate a rich conception of blur. The main, but not the only, stimulus to accommodation, its initial system error, is blur information, the element of refractive error—or defocus—now categorized as accommodative error, which takes the form of blur signals to different areas in the brain. The signals are triggered by deviations from tolerated degrees of yet another measure of blur, contrast levels—luminance, or brightness, gradients around the fovea. As the signals reach the brain, tolerance thresholds help provide cognitive cues about, for instance, fixation (interest), distance, or motion. Blur can contribute, after all, cognitive functionality, not just methodological value.

The same kinds of models can also distinguish between (optical) dioptric defocus and depth of focus. Depth is characterized by a range of values of optical defocus, or refractive error, that the subject cannot distinguish, that is, they correspond to the same phenomenological, subjective experience. In addition, the blur tolerance associated with depth of focus increases with age. For small amounts of blur above that range, the so-called just-detectable blur circle, a compensation mechanism is activated in the form of a process of reflex accommodation; beyond those, accommodation is partly voluntary. Additional ranges of blur values are the result of eye movement and fast micro-oscillations in the accommodative muscle activity; this functional degree of blur serves the cognitive purpose of settling on an optimum level of accommodation ([44]: pp. 119–120). Moreover, the accommodation mechanism is said to respond to the magnitude of blur in the blur pattern, but not to yet another aspect of blur, its direction, associated with asymmetries in the pattern. Accommodative and refractive conditions are not the only causes of blur, but they are the predominant ones.

42.3.4 Measurement Models of Blur with Functional Tests and the Calls for Standardization

A different model, at the empirical and clinical heart of optometry, operationalizes the concept of vision sharpness, and thereby of blur, with a numerical functional test. It is effectively a measurement model of visual acuity as visual performance, and while it aims at descriptive and predictive value, it plays, unlike the optical and neuroanatomical models, no explanatory role. This functional model of sharpness (and blur) is based on at least four connected elements: (1) a conception of sharp vision in terms of functional performance; (2) a material typographical standard, a chart with standardized visual targets; (3) a numerical metrical standard such as diopters, operating as a unit of measurement; and (4) a numerical clinical standard establishing a benchmark of normalcy. The technique depends on the patient's input and therefore is an instance of subjective refraction. The main purpose of applying the model is to provide guidance for clinical intervention, whose goal is defined in similar, functional terms, namely, to restore a desired level of functionality by optical means, namely, by reducing the degree refractive error associated with the diminished visual performance.

More specifically, acuity is adopted as a functional representation of sharpness in terms of the capacity to perform certain visual tasks, primarily a capacity of spatial resolution that has received in turn different mathematical representations, for instance, "the angular size of detail that can just be resolved by the observer" ([43]: p. 217). Resolution is a form of recognition, that is, of identification or categorization that discriminates between two visual elements as different in relation to some spatial property we believe distinct. Whether the cognitive uncertainty associated with blur is also linked to predictive tasks or decision-making is a matter for yet another kind and level of modeling. In basic visual terms involving distributions of light such as a light spot against a dark background, the task of perceptual resolution becomes a task of contrast discrimination, the discrimination of differences of brightness (or luminance). (The optical and anatomical models establish that the size of the image is a matter of diffraction patterns and the size of the photoreceptor and the difference between the amount of light detected by one receptor and the one detected by its neighbors).

From that standpoint, the minimum resolution is the least separation recognized between two adjacent points or lines. One common target for measuring such capacity is a grating with alternating patterns of brightness representing a set of lines. At this quantitative basic level of description, visual acuity is defined as the capacity to perform minimum resolutions tasks, and its quantitative expression is the angular size of the smallest target resolved (ibid.).

For clinical, not explanatory, purposes, then, the measure of visual acuity must be optically informative, so that it suggests a measure of defocus, or refractive error, and the quantity of compensating lens power or focal distance to provide the sharpest retinal images. Yet, the relation between acuity and the optics of refractive error is a complex—messy—matter, involving multiple optical factors such as, not surprisingly, contrast sensitivity, pupil size, age, astigmatism, and other aberrations (pp. 238–42)–and this in addition to the constellation of different concepts, models, and metrics.

Contrast sensitivity (and threshold), for instance, has been touted as another valuable proxy for visual functionality alongside visual acuity. In the psychophysical tradition recovered in the 1950s and 1960s, it was introduced with Weber's expression, $C = (L_b - L_t)/L_b$, where L_b is the luminance of the background and L_t of the target. In optical analogy with the eye, the psychophysical standard was applied to determine the sensitivity thresholds of photographic cameras and film. Sensitivity charts are sometimes produced photographically, and the print displays gradually fading grating patterns or letters (the Pelli-Robson chart simulates different virtual experiences of letters on a Snellen chart). Both as a measure of visual performance and in its role as a theoretical or empirical (metrical) representation of sharpness (and blur), the relation of contrast sensitivity to visual acuity scores is hardly simple and general enough, even as an approximation ([45]: p. 247).

This basic level of resolution facilitates, in turn, the application of more abstract, related descriptions, and their use in different kinds of tests. For example, most clinical tests of visual acuity are introduced with the aid of standardized charts as "recognition tests that determine the smallest symbols, letters, or words that can be identified correctly" and are often called optotypes (p. 218). Different visual targets, displayed in printouts or digital screens, and different numerical measurement standards have led to different measurement tests for the functional notions of sharpness and blur. The most widespread in clinical settings are the Snellen chart and the Snellen fraction. The familiar test is based on the complex task of recognition at two levels, resolution of the image, and identification of each letter (and the additional motor task of communicating those different judgments) [46].

Following the initial proposals of standardized tests by Heinrich Küchler in Germany in 1843 and Eduard von Jäger in Austria in 1854, Donders, in the Netherlands in 1861, commissioned a measurement tool from his colleague the surgeon Hermann Snellen. The enduring challenge of standardizing the test was, since the beginning, culturally and socially informed, targeting a literate population and requiring a typographic choice among current printing styles. It was quickly adopted, like any measurement convention, to serve the practical needs to standardize established practices, for instance, the British Army's interest in standardizing the recruitment of soldiers [47].

The Snellen fraction establishes the measure of visual acuity as the ratio of the test distance to the distance at which the patient recognizes a letter whose height subtends an angle of 5 minarc. Snellen's choice in 1862 of this quantity to define "standard vision" was, like Kepler's studies of vision and other later developments, linked to astronomical practice, in particular, to Robert Hooke's determination in the 1660s that the human eye could discriminate double stars with a minimum angular separation of 1 minarc ([38]: p. 195). When distance is measured in feet, the standard score adopted as reference is 20/20 (not a statistical average, but the lower end of the normal range). From the inverse of this ratio one can determine yet another measure of resolution—or sharpness and blur—the minimum angle of resolution (MAR) (20/20 corresponds to 1 minarc), the angular size of the smallest letter or optotype the patient can recognize, and the visual acuity rating, VAR = 100 – 50 log MAR. As in other metrological practices, also for the clinical measurement of visual acuity there is no single international standard.

As a technique for determining and correcting the refractive status of the eye, subjective methods such as acuity measurements seek to determine the focal position of the eye relative to the outer surface of the retina. The geometrical model is embedded in an anatomical-physiological model that includes the role of accommodation of the lens. The optical determination requires that the accommodation function be at rest or at a minimum. Here a common technique for setting the base level of accommodation is the so-called fogging technique. It involves inducing an increased experience of blur by the uncorrected eye, or, equivalently, a decrease of its visual acuity, to a minimum of at least 20/100, and then proceeding to *unfog* acuity. Here is an example of methodological use of blur, and, I will illustrate below, it has involved in the past a role for photographic images of blurred charts.

The relation between visual acuity and refractive error required for the latter's determination becomes approximately linear only for high levels of defocus. But the relation between magnitude of aberration and visual acuity cannot be generalized, since it doesn't apply to cases of normal optical quality, and the lowest amount of aberrations within a population doesn't correlate with the highest acuity score ([48]: pp. 353–55). The degradation of acuity by defocus seems captured by a simple inverse second-order equation, that is, approximated by the inverse of the square of the measure of defocus (the so-called Blendowske's equation). Visual acuity, more generally, appears determined mainly by the high-frequency end of the contrast sensitivity function, quantified by the so-called modulation transfer function [42].

In such a constellation of concepts of blur, it is important to distinguish between the objective theoretical explanation and the clinical determination through subjective refraction. Successful refraction may be based on invalid assumptions and explanations or else on assumptions such as the sufficient validating role of the patient's subjective judgment and the correlation between acuity and the power of the corrective lens, while committing to strictly false—at least wildly idealized and inaccurate—hypotheses about the explanatory mechanism. One such contested explanatory model holds the validity of Gaussian two-dimensional linear optics for matching independent orthogonal meridional planes, but the meridians typically don't match [49].

42.3.5 The Rise of Mathematical Wavefront Models of Aberration and the Role of Scientific Technologies of Vision

Optical models have contributed complex mathematical tools beyond elementary geometrical ray optics to treat aberrations. Application of such developments in practical optics focused primarily on lenses and optical instruments, prompted, as already noted above, especially by challenges posed in astronomy and microscopy.

In the late 1820s and throughout the 1830s, the Irish mathematician William Hamilton developed a theory of geometrical optics for systems of rays based on the formulation of a characteristic function that connected the coordinate of the points in the object to the coordinates of a corresponding point in the projected image [50–53]. In 1840 the German mathematician and astronomer Carl Friedrich Gauss introduced a systematic treatment of ray optics based on a computational development [54]: paraxial approximation, for rays forming small angles with the optical axis so that trigonometric functions are approximated by linear functions of the angles. Gauss's geometrical model was based on three pairs of conjugated points on the optical axis of a rotationally symmetric optical system (so-called cardinal points: focal, nodal, and principal). This approximation is both empirically adequate and computationally tractable for flat optical surfaces or small portions of spherical ones.

The invention of photography, around 1839, challenged practical optics to produce objectives with apertures and fields of view larger than those of telescopes. Portrait objective lenses used for early daguerreotypes caused distortions and the level of luminance made necessary long exposure times of 10–30 min. Along the way the practical challenges provided the more theoretical challenge and the opportunity to extend the mathematical models of Gaussian optics beyond its defining small-angle idealization. In Vienna the Hungarian applied mathematician Joseph Petzval did so considering higher-order terms, with higher powers of angles, in Gauss' expansion [55, 56]. In 1840 he applied earlier calculations to the design of a new portrait objective that corrected for calculated distortions and shortened exposure times dramatically.

On the basis of Gauss' geometrical theory, also reported by Listing and Helmholtz in Germany, James Clerk Maxwell in Britain combined his interest in geometry (and Gauss) and a commission to write a book on optics to formulate a general theory of optical instruments. Between 1856 and 1858, he introduced a fundamental concept of a (optically) perfect optical instrument and used it to clarify and classify a set of "defects" (aberrations) and to organize a set of general laws.

Maxwell characterized a perfect optical instrument—or optical perfection—in terms of three conditions: (1) every ray of light emerging from a point of the object converges at, or diverges from, a point of the image; (2) from a plane surface of an object perpendicular to the optical axis of the instrument results a plane image on a surface perpendicular to the same axis; and (3) the image produced is geometrically similar to the object regardless of changes in size due to magnification or reduction ([13]: p. 272).

The failure of each condition represents a different type of geometrical aberration. The failure to meet the first condition, with no common focus for the emergent rays, characterizes astigmatism. The failure to meet the second represents field curvature. The failure to meet the third represents distortion (ibid.). The violations distinguish five aberrations: astigmatism, spherical aberration, field curvature, coma, and distortion.

Based on the conditions of perfection and empirical results, Maxwell showed, among other general results, that, if the instrument produces a perfectly focused image of an object on a place perpendicular to the optical axis, it will produce perfect images for all objects also on a perpendicular surface; also that to produce a perfectly focused image, the angular magnifying power must be 1, and the linear and longitudinal magnifying powers must be equal to the ratio of refractive indices in object and images space, which in air is also 1 (pp. 273 and 283).

In an equally significant consideration that I will revisit, Maxwell noted that the mathematical theory gets its simplicity, generality, and completeness at the expense of its explanatory value, namely, in terms of a physical mechanism causing the designated effects (p. 273). We can of course suggest a type of partial or geometrical explanatory role for the mathematical theory or else limit its value to its declared roles: descriptive, clarificatory, and classificatory.

The first systematic mathematical theory of aberrations was published in Germany in 1857 by the mathematician and astronomer Philipp L. Seidel [57]. Seidel calculated the expansion of the rays' optical paths by incorporating the first three powers of the angles in Gauss' expansion of trigonometric functions. He could then identify five independent resulting equations and coefficients that he associated with the different aberrations or modes in the power series. For instance, defocus and astigmatism are lower-order aberrations: defocus corresponds to a second-order mode that varies with the squares of radial distance from the pupil center; and astigmatism corresponds to a second-order mode that depends also on the polar coordinate representing the meridian frequency in the angle around the pupil center relative to a reference meridian (with a second power of the trigonometric functions) ([58]: Chap. 9, [59]).

From the standpoint of wave optics, for instance, rays may be associated with wavefronts perpendicular to them so that ray optics can be extended to represent wavelike additional phenomena. Wavefronts may be defined as the arrangement of point in space at which light has oscillated the same number of times since leaving the source; at such points, waves share the same phase and optical path, the product of the physical distance from the source, and the refractive index of the medium of propagation. Wavefront optics was applied first to the performance of optical instruments and only subsequently to the function of the eye as an optical system to provide better objective models and measurements—with so-called wavefront refraction—of blur and other visual distortions. With such models one can describe and predict different kinds and degrees of monochromatic (for a single frequency) refractive error more precisely and accurately, ranging from the so-called lower-order aberrations such as defocus and astigmatism to the so-called higher-order ones such as spherical aberration, coma, and distortions.

Wavefront aberrations correspond to errors determined in relation to the standard wavefront shape of a Gaussian sphere. The difference in characteristic function is the wavefront aberration function. Seidel himself considered the case of a centered system of spherical surfaces. In the original geometrical ray model, the standard of emmetropy, the optimal refractive status, for a human eye, corresponds to the intersection of small-angle rays on the retinal plane. In terms of wavefronts, the standard corresponds to the flat wavefront in the area around the center of the eye pupil (for the same, small-angle, paraxial approximation). The expansion into different polynomials of increasing order based on the power of polar coordinates is the basis for Seidel's different polynomial equations and their association with different geometrical aberrations (with all other coefficients in expansion equal to zero).

Since 1866, the German physicist Ernst Abbe had sought to address challenges in the optical performance of microscopes (in collaboration with the maker of lenses and optical instruments Carl Zeiss). He did so by extending the application of wave optics by means of models of optical effects resulting from diffraction. In particular, he could establish that the higher the number of higher orders of diffraction in diffraction patterns caused by apertures an objective can capture simultaneously, the higher the degree of resolution, and sharpness, of a resulting microscopic image [60].

Wavefront aberration theory with diffraction was developed further in the 1930s by the Dutch physicist Fritz Zernike [61]. His polynomial expansion of the aberration wave function is defined over a symmetrical circular disk with a unit radius. The polynomials represent possible shapes of aberrated wavefronts, including the lower- and higher-order known kinds described also by the first terms in Seidel's power expansion. Zernike's polynomials can be classified, like Seidel's, in terms of their radial order and meridian frequency; the first 21 corresponding to the first 5 orders and meridional frequencies ranging from −5 to 5 form a well-known periodic table of possible wavefront surfaces. The polynomials' coefficients can then be used to establish the magnitude of defocus, and blur, equivalent to the same magnitude of wavefront error per pupil area produced by higher-order aberrations—associated with higher-order modes.

Zernike's polynomial descriptions of the sources of blur and distortion play an important role in mathematical theory and computational simulations, in particular for the purpose of classifying, predicting, and, for practical guidance, balancing aberrations in lenses and the human eye [58, 59]. It is a separate and subtle issue I will revisit in relation to the computer simulations of retinal images whether the polynomials carry also any explanatory value—for instance, by what criterion of explanation?

The measure of wavefront error in the application of this mathematical model is typically the statistical root-mean-squared error calculated over the pupil. This is a measure of wavefront flatness and therefore of image quality. Accordingly, the standard of optimum status for a human eye, with the optimum focus, or minimum blur, corresponds to the effective minimum of the wavefront error function, ideally zero. The geometrical representation of the shape of the wavefronts is based on differences in optical-path difference, or phase difference, and the determination of three variables—wavefront phase, curvature, and slope—so that the null path or phase difference, or error, with no resulting interference effects, corresponds to optimal image quality. This model provides criteria of wavefront quality in terms of different flatness metrics. The different metrics are used to quantify different aspects of image quality, in different conditions, and different aberrations as a guide to clinical intervention. For instance, the ratio of slope over eye-pupil height yields the measure of longitudinal deflection or defocus that represents and explains optically the basic experience of blur [62].

Again, as in the case of neurophysiological models, also in the application of the mathematical models of geometrical aberration, there seems to be a difference between the mathematical-physical prediction and subjective judgment: the reported minimum blur or best focus differs from both the Seidel and the Zernike standard, lying in between. This difference raises the issue of the varieties of concepts and measures associated with different dimensions of image quality—edge sharpness, contrast, resolution, etc.—and the issue of the difference between the objective retinal image, the basis for objective refraction, and the observer's subjective experience, the basis for subjective refraction. The difference between the two restricts the role of subjective refraction as the gold standard for evaluation objective methods ("To judge the success of an objective method of refraction requires a gold standard for comparison" and the "most clinically relevant choice is a subjective refraction performed for Sloan letter charts illuminated by white light" (p. 332)). Under certain conditions, such as when the variability in results—the precision—of objective and subjective methods match, researchers have defended objective wavefront analysis as the new gold standard of refraction (p. 338, [63]: p. 310). Below I will point to a similar extension of the methodological project in the comparisons of psychophysical experiments and computer simulations in the case, for instance, of starburst blur [20, 64].

The geometrical model is extended further by the mathematics of Fourier transformations to so-called Fourier optics. The representation of the projection of a point source is given by the mathematical distribution of light intensity called the retinal point-spread function. The degree of spread of a point of object is a mathematical model of blur and a metric of the quality of the projected image. The ideal quality level is set by the unavoidable Airy disk. Different metrics are available for both the spatial compactness of the image spread function and contrast (and for images beyond points, by complex composition of the idealized point functions and metrics) [38, 39, 59, 62]. The visual counterpart to the retinal point-spread function is represented by integrating a mathematical model of the neural activity that filters the spatial distribution of the retinal stimuli (for instance, by adding higher weight to areas of higher brightness contrast, or figure borders, over uniform backgrounds). The result is the so-called neural point-spread function.

For grating objects characterized by sinusoidal patterns of spatial frequency, the frequency determines the image contrast (represented mathematically by the so-called modulation transfer function) and the later spatial phase shift (represented by the so-called phase transfer function). Each may be modified by neural functions in order to represent the subjective, perceived image. Together, they constitute the Fourier transform of the point image (the so-called optical transfer function, which also represents a metric for image quality). For dioptric (diffraction-free) defocus blur, the predominant kind as in myopia, the point-spread function (or blur kernel) is a cylinder whose projection on the retinal plane is the blur circle. But other functions have been suggested to model other kinds of blur and their sources, for instance, a Gaussian blur or kernel is associated with so-called low-pass filtering in the neural pathway resulting in the subjective retinal image [42]. This model is an effective tool especially for image processing with the aim of reducing image noise and detail [65].

In linear systems theory, a theorem based on the convolution operation states that the retinal image is the convolution of the point-spread function for the optical image with the original image [38, 39]. Also in this context, blur is methodologically valuable as a source of information: the use of phase retrieval algorithms such as the so-called Gerchberg-Saxon applied to the point-spread function allows the determination of wavefront aberration; in this case, however, it provides a measure of optical error for the clinical purpose of correcting it [66].

It is worth noting that while the defocus can induce the loss of contrast that results in subjective blur, defocusing a grating does not produce any phase shift, except a complete phase reversal known as spurious resolution [67]. Often low contrast images corrected for spurious resolution are still recognizable, that is, they enable higher-level activities of categorization such as reading.

The measurement and calculation of aberration error are based on the difference between the trajectories of incident and reflected rays relative of a reference beam and a single retinal location. The angular defection of light rays is measured at different locations on a grid with an array of microlenses set over the pupil (Hartmann screen) with a video-sensor (Shack-Hartmann aberrometer). The results then form a map of angular deflections across the pupil that is transformed into a corresponding map of wavefront error, or aberration map [59]. Now, the methods of objective wavefront refraction are evaluated by comparison with the results of subjective refraction, still considered the gold standard, despite the multiple sources of variability and uncertainty (p. 783), for instance, the difference between the predicted defocus and the actual subjective blur might be due in part to the difference between the monochromatic model of objective refraction and the polychromatic character of subjective refraction with white light.

The fact that objective measures seem poor indicators of subjective quality is also compounded by the fact that subjective judgment presents contextual effects linked with, for instance, complex stimuli [68]. All the mathematical models presented above, whether geometrical or algebraic, introduce a precise representation of blur, but its application results in varying degree of accuracy and, in cases of subjective disagreement, unquantifiable variance.

42.4 Blur Drawings and Photographs: Standards, Contents, and Uses

42.4.1 Blurred Ophthalmic Photography

Fuzziness expresses challenges of categorization or recognition, whether phenomenological kinds of fuzziness—vagueness or categorial uncertainty about phenomenological categories—such as blur caused by optical aberrations, or in more abstract or technical interpretations, for instance, diagnostic medical descriptions or legal judgments. The latter kind typically rest on judgments of the former: The boundaries, shape, size, and color determinations of a skin condition such as a mole may form a feature vector that leads to further determinations about whether it is, for instance, a case of melanoma. It is the cognitive practice I call connected categorization [1].

The working connections that make additional categorization possible are not always simple inferences, or strict dependencies, correlations, learned cues, or habits—often associated with a certain context or situation. When technology, not just brains, is involved, there may be in place also different rules or connections, some opaque, others transparent—so-called supervised or curated cases—that may be the product of clustering techniques or some form of ordered chain of inferences supported by theoretical, conventional, or empirical commitments.

Still, one precise, determinate categorization—shape, color, etc.—may not be sufficient to establish another that is connected and equally precise; and vice versa, a case of blur in the boundaries or spatial details of an image may still contribute to a precise additional categorization. It is a matter of availability of determinate connections or the application of one of the categories involved.

This situation extends from mental or retinal images caused direct or aided observations of systems or events to external pictures of symbolic data and analogical records, as in the case of photographic pictures and other visual displays. The images recorded, displayed, and reproduced in different material media are the actual objective—intersubjective—visual working objects produced, interpreted, and used in scientific practices, even when, a explained in the earlier sections, it is the former cases that are the object of theoretical and clinical interest.

In the case of photographic images, I will take them to be photographically produced pictures in a material medium of support that present certain images, or optically captured images and produced analogs, quite independently of the intervening image processing or the medium of display or record, whether a digital screen or a print. In fact, even in case of computer-produced test images, some researches have expressed a marked preference for using photographic printouts on the grounds that they don't introduce certain aberrations—e.g., of the so-called moiré type—that might compromise the results of the tests [67]. Digital image capture, using electronic recording of light at an array of photosensors, is typically classified with film photography as a kind of photography, only the "writing with light" is now a digital affair ([69]: p. 128).

Pictures of blur vision include pictures with images that we may generally consider themselves fuzzy or blurred. In particular, fuzziness in the application to images of phenomenological categories of spatial features involving levels, kinds, or distributions of brightness—including colors—are not uncommon, regardless of the uncertainty or vagueness in any additional categorization for which cases of blur constitute cues or data. As I argue throughout this essay, these kinds of pictures have long been a limited but valuable resource in optometry and ophthalmology.

Their use and availability in the sciences are partly an expression of the use of pictures in general and in particular of photographs. By the late nineteenth century, objective external photography of anatomical and technological elements had begun very slowly to supplement the reliance in textbooks, atlases, and journal articles on printed drawings, both naturalistic and schematic. Technical challenges, quality of pictures, and publication costs could hardly justify replacing or supplementing hand drawings. Occasionally, authors chose to publish sketches of photographs rather than photographs themselves, even when the photographs were displayed and described at conference presentations [70].

In an added rhetorical effect, the realism of photographs played with new force the drawings' role of illustrating and circulating established and novel notions. And just as significantly, it played the role of presenting empirical observations that, unlike drawings, served also the enhanced role of supporting evidence by including the viewer in a community of virtual witnesses. Photographs, unlike drawings, could be used also as measurement devices. An example of the latter in ophthalmology is the keratoscope—or corneal disk—first introduced in 1896 by the Swedish ophthalmologist Allvar Gullstrand, a set of concentric circles projected onto an eye's cornea and photographed in order to use any recorded distortions to determine the cornea's curvature (Fig. 42.5). Another example was the use of photographic pictures, introduced in 1889, to measure the diameter of the pupil with more accuracy and convenience, based on knowledge of the scaling factor introduced by the image (Fig. 42.6).

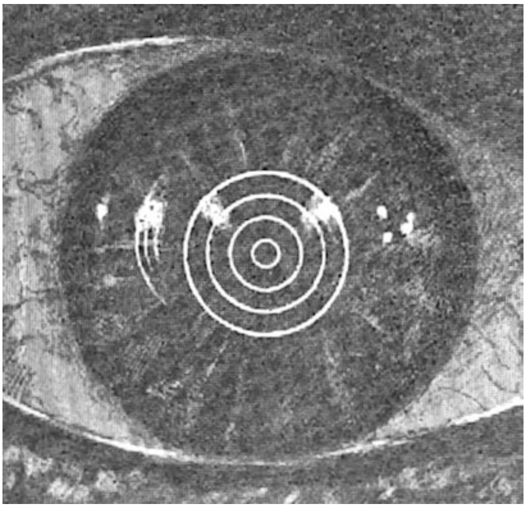


Fig. 42.5 Photographic reproduction of Gullstrand's keratoscopic disk, mapping corneal topography (from Lagrange and Valude (1904), *Encyclopédie Française d'Ophtalmologie*, vol. 3, 100, Fig. 104)

The dominant focus of published pictures on anatomy and technology followed in the wake of the new materialism and scientific naturalism that, as Maxwell had noted, entered the domain of psychology of cognition with models and methods of physical optics, anatomy, and physiology. Along with physics, vision research and treatment were adopting medical standards and entering medical institutions. The use of photographs followed the same trend, at least to the extent that it could be considered more effective than the traditional use of drawings. Photographs and their schematic reproductions initially portrayed seldom any instruments, and tended to depict, instead, anatomical elements such as sectioned eyeballs, in vivo patients' faces with abnormalities, anatomical details serialized form tracking the evolution of conditions or the effect of treatments, microscopic tissue structures and, my main topic below, images that were distinctive of different eyesight conditions. Then, throughout the twentieth century, advances in technology and techniques as well as anatomical features became the primary target of photographic illustrations.

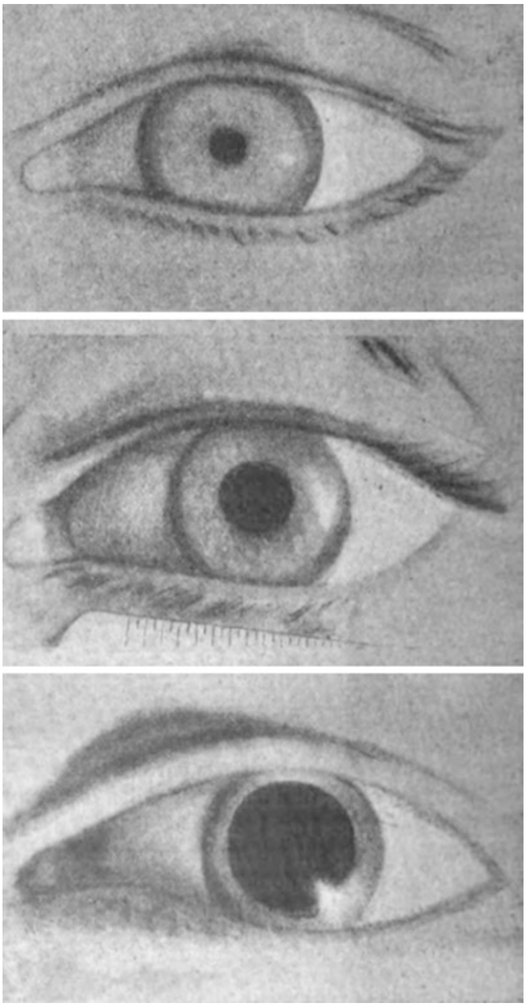


Fig. 42.6 Drawing reproduction of the use of photographic pictures of the pupil to measure its diameter (from Lagrange and Valude (1904), *Encyclopédie Française d'Ophtalmologie*, vol. 3, 814, Fig. 517)

As Daston and Galison have noted in their examination of mechanical objectivity, the naturalistic look of photographic representation of particular entities, anchored in detail and variety, faced the challenge of contributing both realism and generality [4]. The photograph presented visible features of individual entities and also stood, even if confusedly, for their general kind. For the sake of safety of presentation, general models of structures and processes were illustrated with diagrammatic illustrations whose schematic style contributed generality and intelligibility of a more basic truth (besides printing convenience) [5, 6, 71]. Still, the same mechanical objectivity behind the photographic realism of authenticity has often conflicted with the realism of its verisimilitude [4]. The use of diagrams extended their formal, but visible, geometric objectivity to the recording of experimental results (the history of diagrammatic images is long [72–74]).

Generality and verisimilitude have stood in a methodologically uncertain position, between depicting—that is, distinguishing, resolving, identifying—too many visual details and depicting too few. It is not surprising that, to this date, detailed photographic images are presented next to diagrams in photograph-diagram pairs, or with the diagram superimposed for the purpose of visualizing the selective emphasis, the photograph illustrates with too much realism [75]. In particular, ophthalmology texts are rife with diagrams composed of sharper boundary lines and arrows that selectively isolate and identify particular anatomical aspects or structures; and they do so pragmatically, for the sake of both information and, in clinical setting, guiding intervention.

42.4.2 Fundus Photography: When and Where Is the Picture Too Fuzzy?

A similar sentiment about the value of additional control over photographic imaging was expressed around the mid-twentieth century in relation to retinal photography, or fundus photography; it was a defense of the complementary functions of the "ophthalmic artist": "although realism is imparted, the profusion of detail presented may prove distracting and results must be carefully interpreted" ([76]: p. 99). In addition, the author continued, "the artist on the other hand can be selective in rendering ophthalmoscopic appearances, eliminating transient reflexes and mild opacities" and "minor haziness" (ibid.).

Helmholtz's introduction in 1851 of groundbreaking ophthalmoscopic techniques to observe the back of the eye prompted a sustained interest in fundus photography among both researchers and clinicians. Well into the first decade of the twentieth century, however, atlases still relied on lithographic pictures. Early histories have reported valiant but failed or only partly successful attempts at fundus photography in the 1860s ([77]: pp. 1–2, [78]: pp. 190–91). Only in 1886 did William T. Jackman and J.D. Webster in London published the first in vivo pictures of a human retina, even though showing artifacts and a fuzzy uniformity (Fig. 42.7) [79].

After numerous attempts at improvements ([77]: pp. 3–29), in 1899 the Austrian doctor Friedrich Dimmer displayed before participants at the IX International Congress of Ophthalmology in Utrecht the highest-quality fundus photographs they might have seen, produced with powerful carbon arc illumination ([79]: pp. 102–7). A French colleague, the microscopist Louis Dor, followed by introducing an application of color-photography techniques by the Lumière brothers (like Dor, also of Lyon) to color microscopic photographs of the retina (p. 110). In 1907 Dimmer published a manual along with the earliest photographic atlas [77], with taxonomical and diagnostic roles, featuring images of normal cases distinguished from abnormal ones (Fig. 42.8).

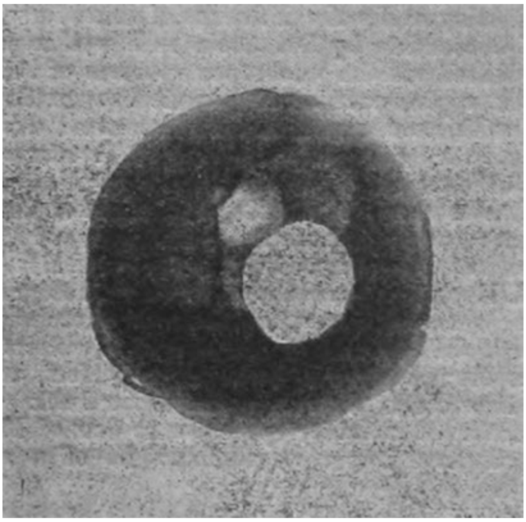


Fig. 42.7 Photographs of a human retina by W.T. Jackman and J.D. Webster (from Jackman and Webster (1886), "On Photographing the Retina of the Living Human Eye," *The Photographic News* 23, n. 275 (May 7, 1886), 293, Fig. 4. With an artifact below the white spot corresponding to the optic disc)

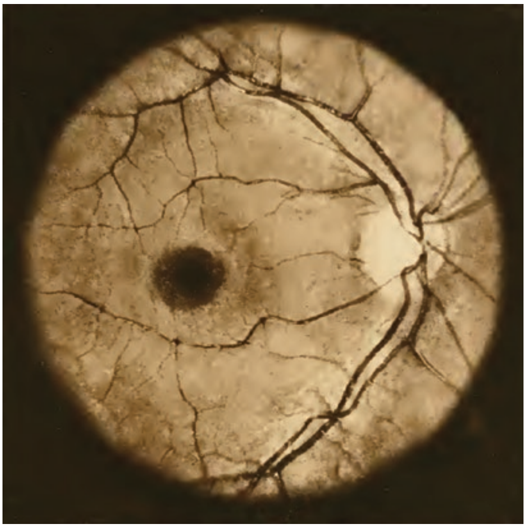


Fig. 42.8 Photograph of a human retina (From Dimmer (1907), *Die Photographie des Augenhintergrundes*, Plate XIV, Fig. 1 (Reproduced in print as a heliogravure))

The early successes of Dimmer, Walther Thorner, and many others indicated that the research, educational, and clinical values of photographs relied on resolving the tension between the authenticity and realism—the connection to some independent reality of the object of interest—defined by their mechanical objectivity, on the one hand, and virtues such as "realisticness," a recognizable realistic look, precision, accuracy, and optimal informativeness, on the other. The latter set presented its own internal tensions such as between precision and informativeness—effective, not complete, realism—, as uses of diagrams and artistic manipulations showed (the familiar case of realistic maps may be instructive here). But it was supported by the minimal expectation of the observer's subjective recognition or recognized similarity, at least according to the standards set by the improved techniques of direct observation and their available pictorial records. Manipulation, control, and processing could be used at the service of effective realism.

Independently of electronic (digital) and computational image processing—for the sake of recording, storage, transmission, and effective manipulation—ophthalmic photography has come a long way to meet new scientific and clinical expectations. And contemporary retinal photography has established its effectiveness on the established performance of complex tasks.

One modern practical manual identifies a minimal set that lists, for just one kind of camera, 19 tasks that deserve careful attention, forethought, decisions, and preparation: (1) prepare the room, (2) adjust the eyepiece, (3) plan the photographs, (4) escort the patient, (5) inform the patient, (6) position the patient, (7) position yourself, (8) establish fixation, (8) position the illumination system, (9) adjust the joystick, (10) select the area of interest, (11) select the angle of view, (12) check the focus, (13) double-check everything, [14] expose the film, [15] close the session, [16] process the film, [17] edit, [18] label and review the photographs, and [19] deliver the finished product ([69]: pp. 23–34). Setting the eyepiece correctly alone, and the reticle with reference lines, involves following eight tasks: (1) have your eyes corrected for their best visual acuity; (2) eliminate any subject matter from the camera's field of view; (3) set the eyepiece adjustment to the maximum plus diopter setting; (4) relax your eyes; (5) peer through the viewfinder, and begin turning the eyepiece ring towards the zero setting; (6) stop rotating when the reticle is just in sharp focus, (7) repeat, repeat, repeat; and (8) check the eyepiece setting and reticle before each patient (p. 25).

Some of the steps and additional troubleshooting instructions address explicitly the maximization of sharpness and the minimization, or elimination, of blur. The authors offer a general standard:

> Sharpness in a photograph is a visual phenomenon that is difficult to quantify. Both contrast and resolution play a role in our subjective evaluation of sharpness. An image is described as sharp when the borders defining the subject are distinct and clear. An unsharp image contains borders between adjacent areas that double, overlap, or are difficult to distinguish. A sharp fundus photograph results when the fundus camera's plane of sharp focus coincides with the specific pathology in question [at the relevant specific level of the retina]. (p. 81)

The camera's depth of field, the blur tolerance, will register structures tolerably sharply at levels different from the targeted one in critically sharp focus—on the focus plane. Other structures will inevitably appear blurred even if our anatomic representation includes an idealized sharp definition of its structural edges. Many, such as the macula and the optic disc, however, do not. Categorization or identification will be also uncertain, and often a practical use of sharp diagrams helps for certain examination and diagnosis purposes (Fig. 42.9). It is a pragmatic and contextual matter of means, purposes, and standards whether a certain degree of blur is judged acceptable—whether or not it is also correctable.

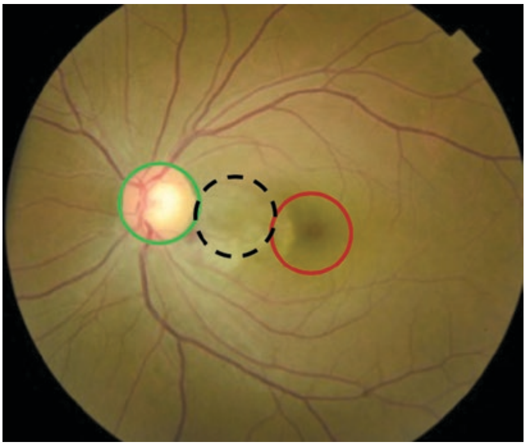


Fig. 42.9 Photographic image of the fundus with a diagrammatic circle for identifying the location and size optic disc (optic nerve) and using its diameter to calculate and identify the location of the macula (Adapted from Tyler, Saines, and Bennett (2003), *Practical Retinal Photography and Digital Imaging Techniques*, 8, Figs. 1–8. Courtesy of Brett King, OD IU School of Optometry)

What can the observer do? For instance:

> On looking through the viewfinder with your dominant eye, you should see a blurry fundus image with an overlapping [sharp] reticle. The image you see will probably be out of focus and may have a crescent-shaped artifact. Focus quickly, knowing that you will make fine focusing adjustments later. The crescent-shaped artifact indicates that the distance between the objective lens and the cornea is nearly correct. An unsharp or fuzzy artifact implies that the illumination system is improperly aligned (p. 28). (Fig. 42.10)

And checking the focus: “Begin turning the focusing knob, and the retinal image will sharpen. While remaining aware of the focusing reticle, keep turning the knob, and the major blood vessels will become sharp. Concentrate on the next smaller blood vessel branches and then the next smaller branches. In very clear eyes, you may be able to distinguish extremely fine blood vessels. Eyes with cataracts or other media opacities may reveal only the major blood vessels. Focus as best you can, remembering that not every patient has clear media” (pp. 33–4).

In addition: “if the edge of the image is cloudy or blurry, either adjust the joystick toward or away from the patient until the whole image is clear, ask the patient to blink twice, or ask the patient to open his or her eyes wider” (p. 39).

Besides the effect of blinking on the refractive property of the cornea and the optical conditions of the observer’s and patient’s eyes, there are additional factors such as compensation mechanisms such as accommodation: “Blurry fundus photographs of patients without media problems are often the result of the photographer accom-

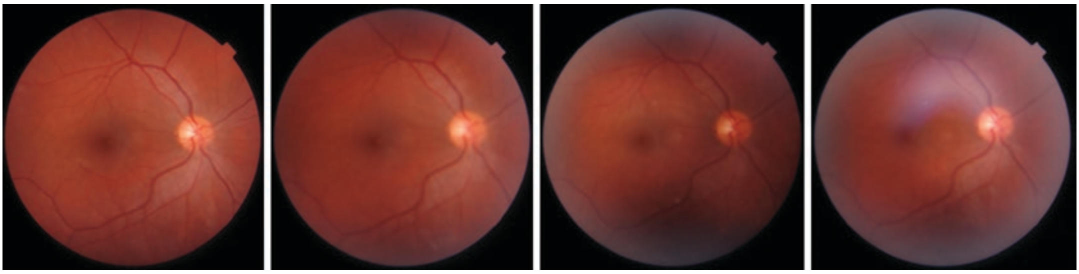


Fig. 42.10 Series of photographic images with increasing sharpness as a result of the observer’s manipulations of the focusing tools in the camera (Adapted from Tyler, Saines, and Bennett (2003), *Practical Retinal Photography and Digital Imaging Techniques*, 29, Figs. 2 and 3. Courtesy of Dawn Meyer, OD IU School of Optometry)

modating during the procedure (…). When you look through the camera eyepiece and accommodate, you might see a shape image of the retina but not see a sharp image of the focusing reticle. If you accommodate to obtain a sharp retinal image, then the optical system of your eye, rather than the optical system of the fundus camera, is used to obtain sharpness. You might attempt to sharpen the image using the focusing knob, but the result will be a blurry photograph" (p. 53).

Thus, there is blur, and then there is blur. The photographic process, or practice, and resulting images and their observation must be considered. Their optical status depends, then, on the application of several criteria of sharpness and blur and the instrumental manipulations and controls to maximize one and minimize the other. The ineliminable blurred experience and representation of objective anatomical structures such as the macula are only one such source, and then the higher-order fuzziness in subsequent diagnostic categorizations. There is fuzziness or blur in ophthalmic photography, then, independently of the representation of blurred vision (although not independently of the conditions of blurred vision).

Generalizing and simplifying, we can identify several dimensions of blur in the practice of objective ophthalmic photography for ophthalmic structures. They correspond to different standards of sharpness and sources of blur often beyond the experimenter's control in the form of compensation or correction:

- Optics: optical defocus and aberrations resulting from the refractive status of optical system, which including the observer's and patient's cornea, pupil, lens, and vitreous.
- Display medium's maximum resolution, e.g., limited by grainy structure of focusing screen material, or the density of pixels in digital displays.
- Recording medium's maximum resolution, e.g., the film sets natural limits on resolution capacity.
- Observer's retina's maximum resolution, e.g., neuroanatomical conditions and diffraction effects.
- Observer's best (corrected) acuity standard, including the perception of the reticle's lines as sharpness standard and ideal physical and physiological conditions such as steady attention both in recording and observing the resulting photograph.
- Visual standards from past or independent observations of the same structure (here the effect of earlier pictures on how details are recognized or categorized cannot be neglected).
- Visual standards from models or idealized representations of the structures, e.g., in this case, anatomical structures such as retinal layers and levels, blood vessel structures, approximate location, size and shape of the fuzzy-bounded macula and optic disc, etc. (often the assistance of diagrams expressing some feature of the conceptions included in available models).

Even in relation to the accuracy and objectivity of visual representations of objective material structures, then, their material and public conditions do not circumvent the fact that sharpness and blur are inevitably subjective and relative considerations that enclose the patient, the photographer, and the photograph viewer in a circle of subjectivity and relativity of perception. Nevertheless, for cognitive and practical purposes, there is an important distinction between (1) seeing blurry, (2) seeing blurred images in a constrained optical setup such as an instrument, and (3) seeing pictures (in a supporting material medium) with/of blurred images, that is, seeing them (optimally) "sharply," on focus, or within the tolerated depth of field [1]. Still, some pictures intended as representations of blurred vision do not look blurry or fuzzy at all (Fig. 42.4). The categorial assessment of blur is relative to a determinate standard, e.g., the assumed exact location of a point or line. Images of blur and, by extension, blurred vision can be thus both precise and accurate. To the extent they are considered blurry yet accurate depictions of a particular visual experience and, by extension, of that kind of experience more generally, the pictures illustrate a trade-off between precision and accuracy—or visual truth.

The resulting photographs are visible working objects, both material and visual models of their target features, phenomena, conditions, or structures. They are used as taxonomical standards for categorizing targets from different standpoints, for instance, of anatomy–identifying anatomical parts–and pathology—as either normal or abnormal, and then more specific conditions. Blur enters the picture here only in the application of phenomenological categories such as edge, shape, location, and color. For considerations of functionality, both the anatomical and pathological standpoints rely on an optical standpoint and its concepts, models, and practices. Then, beyond the goal of taxonomical description, and based on it, the resulting pictures may serve a number of different purposes: communication—including education—detection, measurement, prediction, evidence, and clinical intervention.

Those functions depend, again, on the use of the pictures for different kinds of categorization and representation. Establishing how that works—what is the subject matter or content of a picture and how it is achieved—is a difficult task that cannot involve just pointing to any single and general criterion; different cases may involve different combinations. In discussions of imagery in both the sciences and arts, a number of such criteria have been proposed: indexicality, or systematic causal connection—e.g., a symptom or an indicator, also the declared grounds for the realism and mechanical objectivity of photographs—, similarity—always limited and enabled by contexts and always relative to adopted specific standpoints, exemplars or models—, recognition—with or without explicit considerations of similarity—, conventional symbolism, instantiation of a general kind—or membership in a class—, author's intentionality, application of community-accepted standards, background information or assumptions (supporting interpretation) and, as discussed above, techniques for production based on informed manipulation and control [4, 80–86]. As I argue below, the different criteria do not apply equally to the different kinds of pictures of blur and their uses.

Fig. 42.11 Blurred image of a face in a photorefraction test result (From C.E. Campbell, W.J. Benjamin and H.C. Howland (2006), "Objective refraction: Retinoscopy, Photorefraction, and Autorefraction," in W.J. Benjamin, ed. (2006), *Borish's Clinical Refraction*, second edition (St. Louis, MS: Butterworth-Heinemann), 754, Fig. 18–47B)

One distinctive use of fundus photography, introduced in the early 1960s, serves the purpose of objective refraction by helping determine the refractive status (error) of a subject's eyes. It has the advantage of refracting both eyes in an instant, not requiring any sustained attention from the subject. The camera records light returned through each eye's pupil by reflection from its fundus. To represent, categorize, or detect the eye's refractive adequately requires interpreting the resulting image. The different so-called point-spread methods transform and analyze, differently, the effect of a bright light source at a "point" in the camera lens. In particular, in each different way, they defocus the point-spread reflected image into different shapes and measure their sizes [27]. The defocus and resulting blurred image of the subject's face and eyes are, then, an informative intrinsic part of the process of representation of the refractive status (Fig. 42.11).

Recognition and similarity relative to the sharper image separately perceived of those faces plays no role in fixing the photograph's contents.

Just as in the case of the blur resulting from the selective focus on a specific retinal level, or the lack of sharp boundaries identifying the macula or the optic disc, also in photorefraction photographs, maximal sharpness is not an absolute standard, and blur is not an error to minimize or eliminate. Blur is here, again, central to the photographs' success; even if it is at the expense of verisimilitude or realistic appearance.

42.4.3 Portraying Blurred Vision: Artificial Simulations, Drawings, and Photographs—What Can Drawings Do?

Among ophthalmic photographs, one type stands out featuring fuzziness in a distinctive way, namely, pictures of blurred vision. Their special subject has consequences for their relation to other pictures and their broader significance, such as epistemic virtues and methodological uses. I will show that even their uses and availability as photographs have changed in relation to other kinds of pictures: in relation to other kinds of subjects and other kinds of media and techniques such as drawings and computer simulations.

In relation to their subject, their published availability and use have substantially diminished—even further, that is—since approximately the mid-twentieth century. They have been replaced by images of objective anatomical structures, technological aides, and graphic displays of data and mathematical relations. In relation to their medium of display and process of production, the slow rise of photographs of blurred vision followed the relatively more pronounced availability of subjective drawings of optical and entoptic phenomena, even optical illusions. Such phenomena may have a physical basis within the eye such as floaters, phosphenes, Haidinger's brush, or so-called Purkinje images or varying degrees of causal connection or similarity to "real" physical systems or phenomena, from aberrated blurred perceptions to full optical illusions. They have in common in their subjective character, at least in the sense of a restricted individual access or occurrence that cannot be entirely shared, objectively or publicly except indirectly, through the objective visual representation by material pictures or through verbal communication.

Researches and educators published subjective drawings of different visual experiences that had taken place under a variety of conditions, for instance, different possible aberration conditions. The hand-drawn pictures illustrated reports of such images, often by the authors and experimenters themselves—self-experimenters—such as Thomas Young. When the experimental curiosity, dexterity, and determination were accompanied by graphic skills, as in Young's own case, self-reporting could be a matter of opportunity and added credibility—all the more so on issues of personal experience such as visual sensations. Young's illustrations set a standard that was disseminated along with his (illustrated) contributions to anatomy and instrumentation, especially since the celebrated paper on accommodation of 1801 [34]. He depicted "imperfect images" of a remote light point seen at different distances, with different degrees of imperfect focus, by each of his eyes—he cited Jurin's distinction between distinct and perfect vision—(Fig. 42.9, images n. 31–39; n. 30 represents the image of a very close point source after rubbing the eye). Young subsequently described them as images with different "degrees of distinctness or confusion" ([35]: vol. 1, p. 453). Even when the focus is "the most perfect," he stressed, the image of the light point source is still indistinct and somewhat starry in shape (Fig. 42.12, n. 33) ([34]: p. 87).

In the second half of the century, Helmholtz's landmark *Treatise* developed Young's researches further, incorporating subsequent contributions, including his own. It also featured a few reproductions of hand-drawn retinal images as experienced by Helmholtz himself: for instance, of "star-shaped figure," or "ray crown," of "blurred images" or "diffused images" or "appearances"—Helmholtz experienced in each of his own eyes at different distances from the point source and with different degrees of illumination (Fig. 42.13).

In cases of narrow lines as sources, Helmholtz argued that the resulting effect by composition of point images was the extension of blur in the

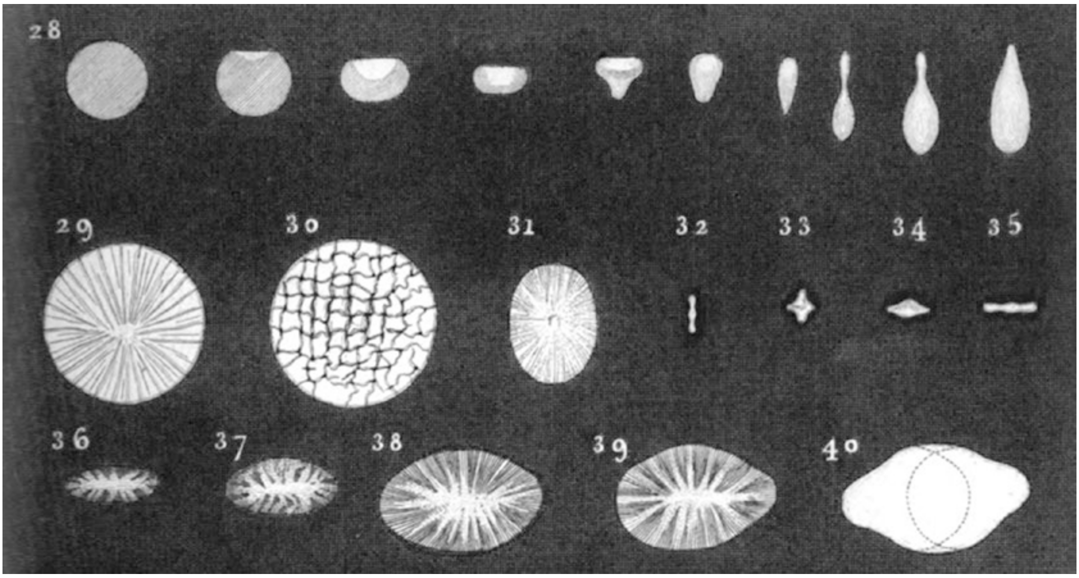


Fig. 42.12 Images of light point sources at different distances (from Thomas Young (1801) "On the Mechanism of the Eye," *Philosophical Transactions of the Royal Society of London* XCI, Plate VI, following p. 88)

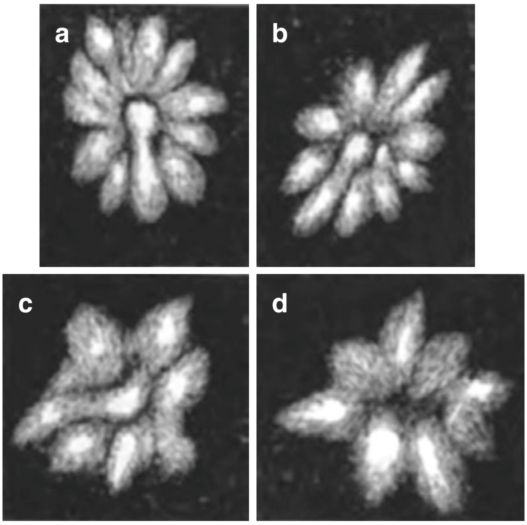


Fig. 42.13 Reproductions of drawings depicting star-shaped blurred images in different eyes (from Helmholtz (1867) *Handbuch der Physiologischen Optik*, 137, Fig. 65)

form of double, or multiple, images, without eye accommodation (also Donders adopted the identification of star-shape or ray-corona blur and polyopia as related symptoms of irregular astigmatism, with a primary cause in the structure of the lens) ([38]: pp. 544–6). As demonstration, in the twofold sense of evidence and intuitive illustration, Helmholtz used a picture of the experience of the juxtaposed sources, point and line, at different distances showing the correlated features of the image of each source in the presence and absence of the blur effect (Fig. 42.14). In addition to simulating Helmholtz's own experiences, the picture reproduces the effect of the demonstration playing the role of a visual guide to following the instructions in order to experience the images. Naturally, it's worth pointing out, the successful reproduction of the effect was relative to his and readers' own eyes' acuity. This relativity is, besides the intersubjectivity, a fundamental feature of the use of blur pictures.

A new project emerged throughout the nineteenth century with modest efforts recording and cataloguing varieties of normal and abnormal sensations and a more systematic work developing and publishing taxonomical, explanatory, and corrective treatments of optical aberrations. Many aberrations, as well as their optical explanations, had been established in different optical systems either subsequently or prior to being identified as contributing to eyesight conditions. Young's early discoveries concerning astigmatism and accommodation were followed by the

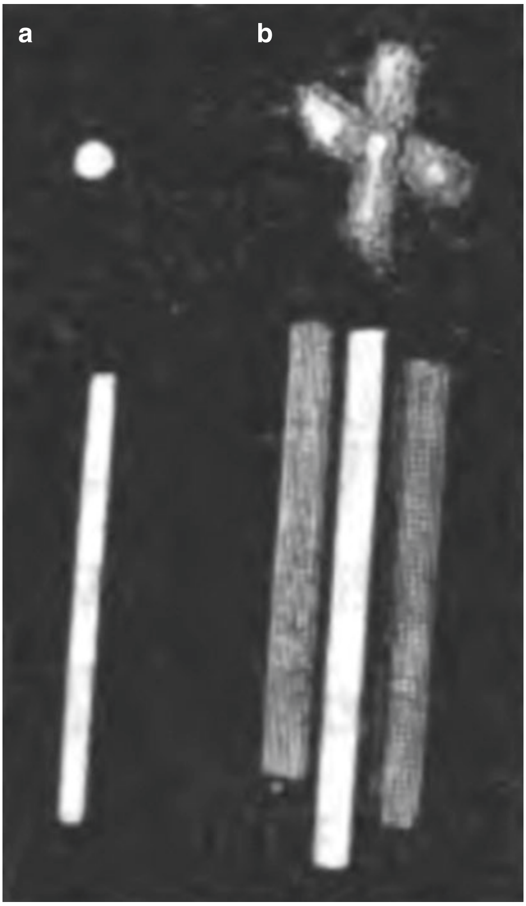


Fig. 42.14 Reproduction of drawings depicting the correlation of starbursts and polyopia as perceived by Helmholtz himself as a result of a difference only in the geometry of the light sources (from Helmholtz (1867) *Handbuch der Physiologischen Optik*, 139, Fig. 66)

more detailed experimental and explanatory work by Helmholtz and Donders in the 1860s. Their optical and anatomical work paved the way for a widespread and sustained effort of education and research on the symptoms, causes, and treatment of regular and irregular astigmatism.

The regular results from two perpendicular principal meridians (lines of maximum and minimum power or curvature), mainly on the cornea, consist in two focal points. The irregular involves non-perpendicular meridians and additional rotational asymmetries in the refracted light beams and, as a result, is characterized by a notable richness of phenomenological effects in the form of irregular shapes, brightness, and colors of the cross section of the refracted beam at the retina, which Helmholtz and Donders presented only by description—that is, chromatic and achromatic spherical aberrations, varying with distances and angles peculiar to each eye, unlike the general circle of diffusion or blur with shape and size determined by the pupil. The anatomical pathology associated with astigmatism, with anomalies of curvature involving the cornea and the lens, escaped simple schematic geometrical models and generalizations that could replace the clinical role of subjective images in diagnosis and, often surgical, correction—especially Albrecht van Graefe's successful techniques introduced also in the late 1860s.

In 1871 Bernhard Steinheim published a report of three successful applications of von Graefe's new surgical techniques for the treatment of irregular astigmatism due to keratoconus or conic cornea [87, 88]. He accompanied the report with lithographic reproductions drawings of dispersion circles by one of the patients, a painter that was both particularly aggrieved by the visual symptoms and observant and skilled at reproducing them (Fig. 42.15). The general scientific use of subjective drawings involved, then, two kinds of reproduction, one by the patient—of her own subjective perception—and the other by the author and the printer to circulate the public version of the subjective image. The images demonstrated results of diagnostic classification and clinical correction: they showed the diagnosed failure of visual acuity and tracked and supported the general reliability of the clinical techniques and of the general test value of the contrast between the particular images, before and after the surgery, indicating recovery.

Steinheim described and justified the clinical, evidentiary, and pedagogical use of the images: "In order to watch the progress of his condition more accurately, the patient drew *a series of sketches* showing how a point, a line, a circle, a star-shaped, or sickle-shaped figure, and the crescent in the sky appeared to him prior to the operation. He represented these very objects again in the second month of his cure. The diagrams show a striking difference, and illustrated the improvement in the visual functions. For this reason I

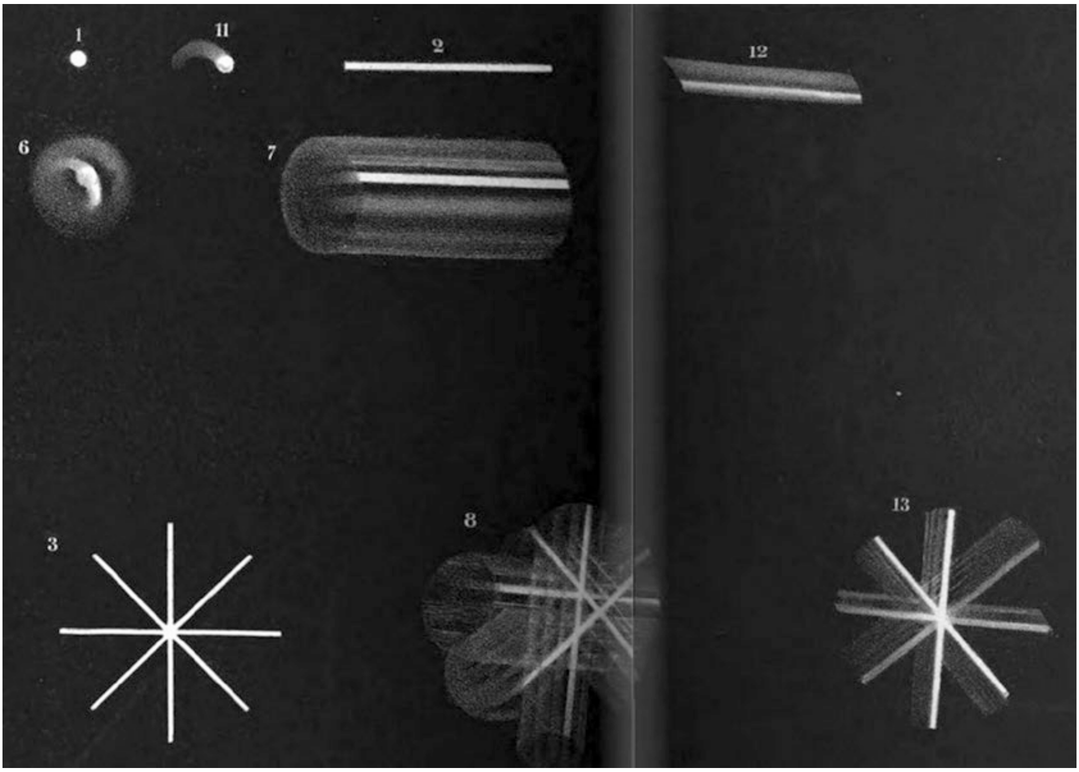


Fig. 42.15 Images of a patient's drawings of points, lines and star-shaped figures before and after surgery for keratoconus, especially Figs. 42.1, 42.11, 42.2, 42.12, 42.3, and 42.13 (from B. Steinheim (1871b), "Keratoconus and its Treatment," *Archives of Ophthalmology and Otology*, 2, n. 1, Table VII)

may be allowed to reproduce these sketches" ([88]: p. 175, [87]: p. 220).

Steinheim's choice of figures suggested a standardization and generalization technique, not unlike Jäger's and Snellen's charts: the use of figure types starting with the simplest, a distant source point, rather than naturalistic simulations of ordinary perception of objects in an environment (with the exception of the astronomical standard of the crescent moon, whose repeated observation was associated with manifestations of aberrations).

The comparatively largest selection of illustrations cataloguing subjective images appeared in two discussions of astigmatism, in *Undersøgelser af Øjet med et Lysende Punkt* (1896) (Examination of the Eye with a Luminous Point), a medical doctoral dissertation by the Danish ophthalmologist Ove Müller Rée (Müller Rée 1896) [89], and in the comprehensive and better-known *Optique Physiologique* (1898) by another Danish ophthalmologist, Marius H.E. Tscherning (Tscherning 1898; the French original was followed by an English translation in 1900) [90, 91].

Tscherning had received a doctorate in 1882 from the University of Copenhagen with research on myopia under the Danish ophthalmologist Edmund Hansen Grut, a former student of von Graefe in Berlin (Bowman, Graefe, and Donders were considered the mid-nineteenth-century founders of ophthalmology). In 1884 Tscherning joined as adjunct director of the ophthalmological laboratory that Émile Javal, another former Graefe's student, had established in 1878 in Paris at La Sorbonne. In 1881 Javal had developed with yet another Scandinavian visitor, his Norwegian student H.A. Schiøtz, a new ophthalmoscope to measure the curvature of the cornea and study astigmatism. At the Sorbonne in 1887, Tscherning earned another doctorate for research with Javal on Listing's law of eye tracking. Javal had also translated Helmholtz's *Handbuch* into French, setting a local standard of eye research. In the same spirit, Tscherning decided to recognize Young's leading contributions to ophthalmology—especially, the development of measurement instruments and the study of astigmatism, accommodation, and color vision—with a French edition of those works [92] that paid special attention to the reproduction of the original woodcut illustrations—which he criticized about George Peacock's edition of 1855 ([93]; p. 323 [90]).

In his research on astigmatism, Tscherning adopted the geometrical principle that the information about all the optical aberrations of the eye was contained in the shape of the image perceived of a point source, that is, the geometry and density distribution of rays—brightness—in the cross section of the refracted beam ([90]: p. 129). The approach had been championed by Young [34] and the astronomer George Biddell Airy—likely from the experience of observing bright celestial bodies—[94] and, after Helmholtz, was endorsed by Donders.

Donders established the distinction between regular and irregular spherical aberration (also named by Helmholtz monochromatic aberration) or astigmatism (after William Whewell's term, reported by William McKenzie, for the phenomenon Young and Airy's identified in their own eyes): regular astigmatism depends on refractive differences among different meridians on the (quasi) spherical surface of the cornea, while irregular astigmatism depends on differences along the same meridian ([38]: p. 451). To determine the perpendicular meridians of maximum and minimum curvature, he adopted two geometrical standards, the deviations in sharpness and length from an image of crosshairs of equal length (Young had used the shadows of needles against the blur circle and the series of slits on his optometer in different directions) and the elliptical deviations from the circular shape of the blur image of a point source—its "diffusion image" or "diffusion spot." The deviations were classified according to a number of indicative shapes derived from the optical model (Fig. 42.16) (pp. 451–52).

While Donders didn't reproduce any such images as reported by an astigmatic observer, he emphasized the diagnostic value of the elongations of the blur circles ([37], p. 454). The reason was clear: "The diffusion-image of a point of light alters, in modification of accommodation, not only in size, but also in form" (p. 470). And he added that polyopia is the result of irregular astigmatism, and in cases of extraordinary irregular astigmatism, the diffusion images are "highly complicated" (p. 455). He pioneered the measurement of astigmatism, introducing testing and corrective roles for cylindrical lenses, after Airy, that focused the refracted rays into focal lines rather than into points. He also distinguished, after Young, between corneal and lens astigmatism, associating the latter with both the occurrence of irregular astigmatism and the discrepancies between objective and subjective determinations of regular astigmatism (pp. 455–56).

Tscherning followed in Donders' footsteps placing emphasis on Young's geometrical standards of representation and testing. More importantly for my argument, he adopted also Young's

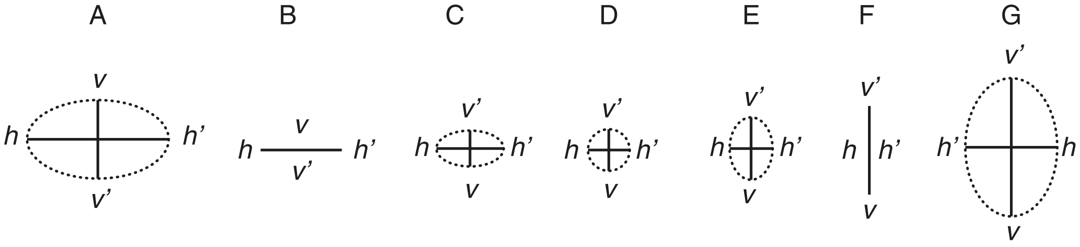


Fig. 42.16 Geometrical figures of distorted blur circles in optical simulations of regular astigmatism (in Donders (1864), *On the Anomalies of Accommodation and Refraction of the Eye*, 453, Fig. 151)

graphic standard of presentation of the multiplicity of diffusion images, linked go different conditions especially distance from the source point against a dark background (called by Helmholtz the method of stigmatoscopy). Thus, the same year he completed the French edition of Young's ophthalmological works, he published a report of the research on astigmatism he had been conducting [95]. He introduced his aberrometer (Fig. 42.17), with a grid that combined the geometric approach of Young's and Donder's to determining the kind and degree of astigmatism based on the contrast among the different cases of peripheral perception of vertical and horizontal lines (Fig. 42.18).

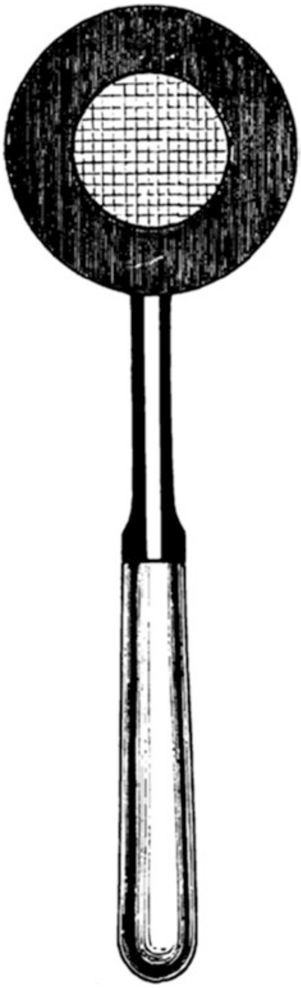


Fig. 42.17 Tscherning's aberrometer (from Tscherning (1894), "Die monochromatische Aberrationen des menschlichen Auges," *Zeitschrift für Psychologie und Physiologie der Sinnesorgane* 6, 458, Fig. 1)

Fig. 42.18 Tscherning's diagram for a case of distortion in the astigmatic perception of the grid in his aberrometer (from Tscherning (1894), 467, fig. 8)

To explain the retinal images geometrically, he introduced a diagram of the optical model of astigmatism, with an irregular geometric distribution of refracted rays along a meridian of a spherical surface. The different rays converge along the periphery and the center (the so-called circle of least confusion) around the optical axis at different distances from the lens (Fig. 42.19). He added a diagram of a section of the beam capturing the appearance of a vertical line at different distances from the center of the blur circle (Fig. 42.20). Then in the major subsequent work, *Optique Physiologique* [90], he depicted also the subjective appearances of the same distortions, as Young had done in 1801, and considered the case of four point sources to map out the varying distributions of light at different distances (Fig. 42.21).

Tscherning did not only follow Young's standard of graphic presentation of subjective appearances; he also gave it a more systematic treatment combining quantitative comparisons (Fig. 42.22) and interventions aimed at discriminating between alternative hypotheses. For instance, he

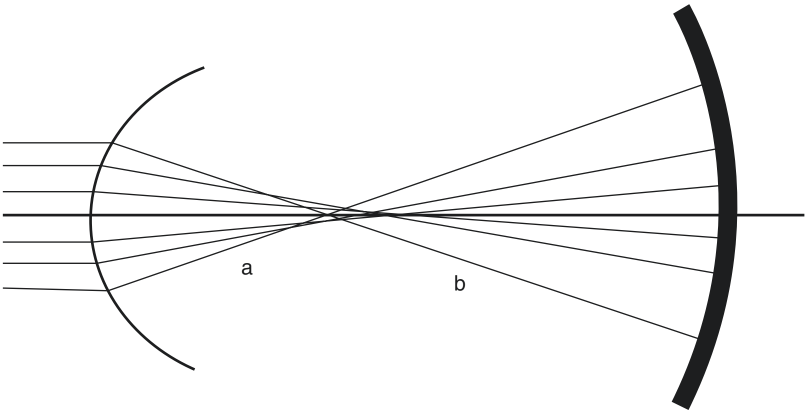


Fig. 42.19 Pattern of multiple points of convergence around the optical axis (from Tscherning (1894), 461, Fig. 4)

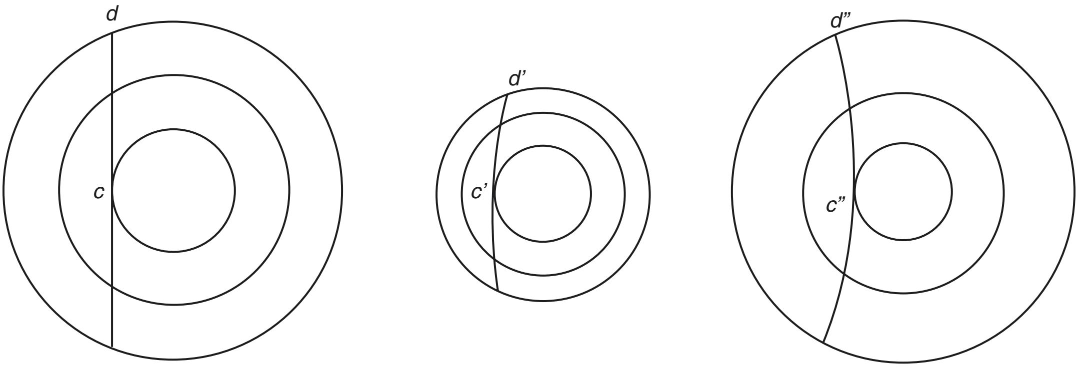


Fig. 42.20 Cross section of the blur circle with peripheral distortions of a vertical line seen in front of a bright point source (from Tscherning (1894), 461, Fig. 5)

covered the upper and lower half of his right eye's pupil without modifying the visual pattern resulting from the exposed part, which contradicted the prediction from a hypothesis based on diffraction. In *Optique Physiologique* he published less crude woodcuts showing more detailed images with the same comparisons (Fig. 42.23).

To assist in the job of expanding the record of astigmatic blur images, he enlisted the help of a visiting fellow Danish eye researcher and Hansen Grut's new doctoral student, Ove Müller Rée. Before arriving in Paris sometime in 1894 to meet Javal, Müller Rée had visited the Royal London Ophthalmic Hospital, where Andrew Stanford Morton had designed another ophthalmometer. After the example of Tscherning's recent research, Müller Rée adopted the use of bright point sources as the best method to study refractive errors and determine astigmatism and its influence on visual acuity ([89]: pp. 4 and 147). As an optical system of lenses, studying the eye's optical performance required paying attention to the blur circle's shape, size, and varying colors and brightness (pp. 2–3). He compiled a more extensive catalog of hand-drawn images experienced himself and by patients with relatively normal eyes and with pronounced regular and irregular astigmatism (for the experiments, accommodation was often controlled with cocaine in order to isolate the optical effects of the unmodified focal power of the lens; on the use of cocaine in ophthalmology see [96]).

Müller Rée organized and reproduced the images in tables following the example of Young's woodcut illustrations of blur spots at different distances, in similar composition and against a dark background [89]. After reproducing Tscherning's geometrical model of spherical aberration with different light distributions at different distances from a lens, the first tables were reproductions of Tscherning's recent version of Young's images (pp. 6–10). The diversity of blur patterns at different distances was key to determining astigmatic aberration.

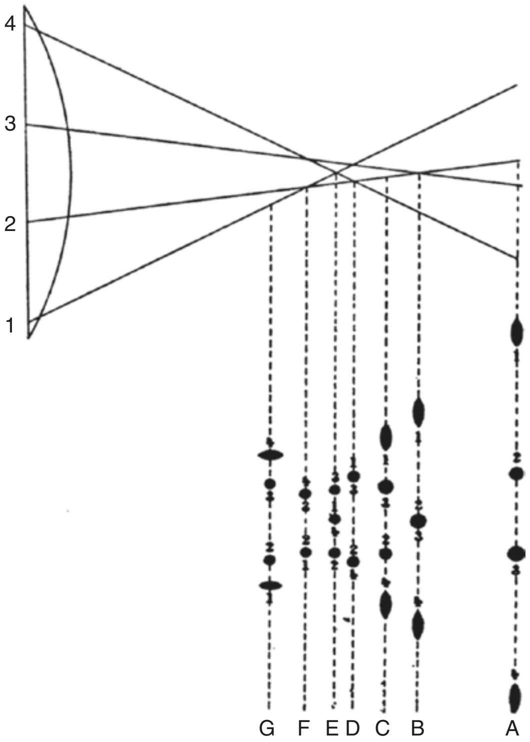


Fig. 42.21 Juxtaposition of the optical diagram of light ray paths from four point sources along the optical axis and a corresponding diagram of the distribution and deformations of the corresponding four blur circles at different distances from the lens (from Tscherning (1898), 92, Fig. 62)

Next he presented several geometrical diagrams of distortions in the grid of Tscherning's aberrometer and tables with sets of drawings reproducing optical standards of astigmatic images from optical simulations combining spherical and cylindrical lenses, after Donders (pp. 33–39). He included a reproduction of Tscherning's diagram of ray distribution as refracted by a lens with spherical aberration marking a number of distances along the tangent plane that would organize the selection and presentation of corresponding blur images for different optical astigmatic conditions, natural or artificial (Fig. 42.24).

Only set against those geometrical and optical standards did Müller Rée reproduce a series of subjective images from drawings by several patients—including, as in Steinheim's study, a painter, colleagues, and himself. He indicated the profession of some observers, such as a painter, an engraver, an accountant, and an engineer, suggesting a potential influence on their eyesight condition and a practical, social value of ophthalmic research.

The first series reproduces the different appearances of a bright point source at different distances from an eye considered normal (minimally astigmatic) (Fig. 42.25).

In subsequent tables, images corresponded to cases of more pronounced spherical aberration, natural or artificial. He included a series of blur images of a point source as seen with his own right eye, which he determined had oblique astigmatism (with rays on the vertical tangent plane

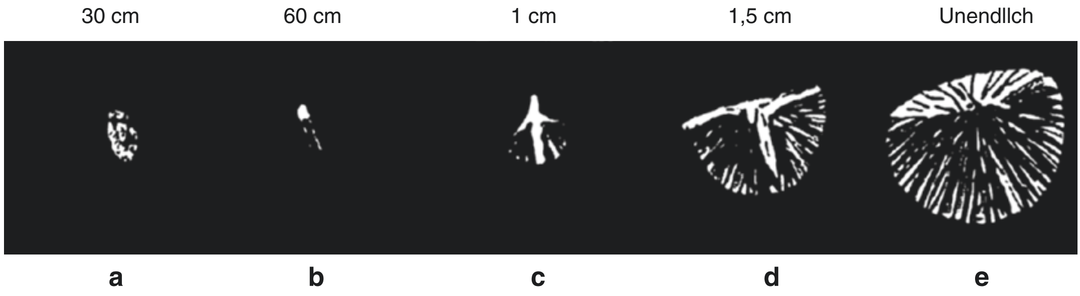


Fig. 42.22 Images of astigmatic blur spots for a light point source seen by Tscherning's right eye at different distances (from Tscherning (1894), 468, Fig. 9)

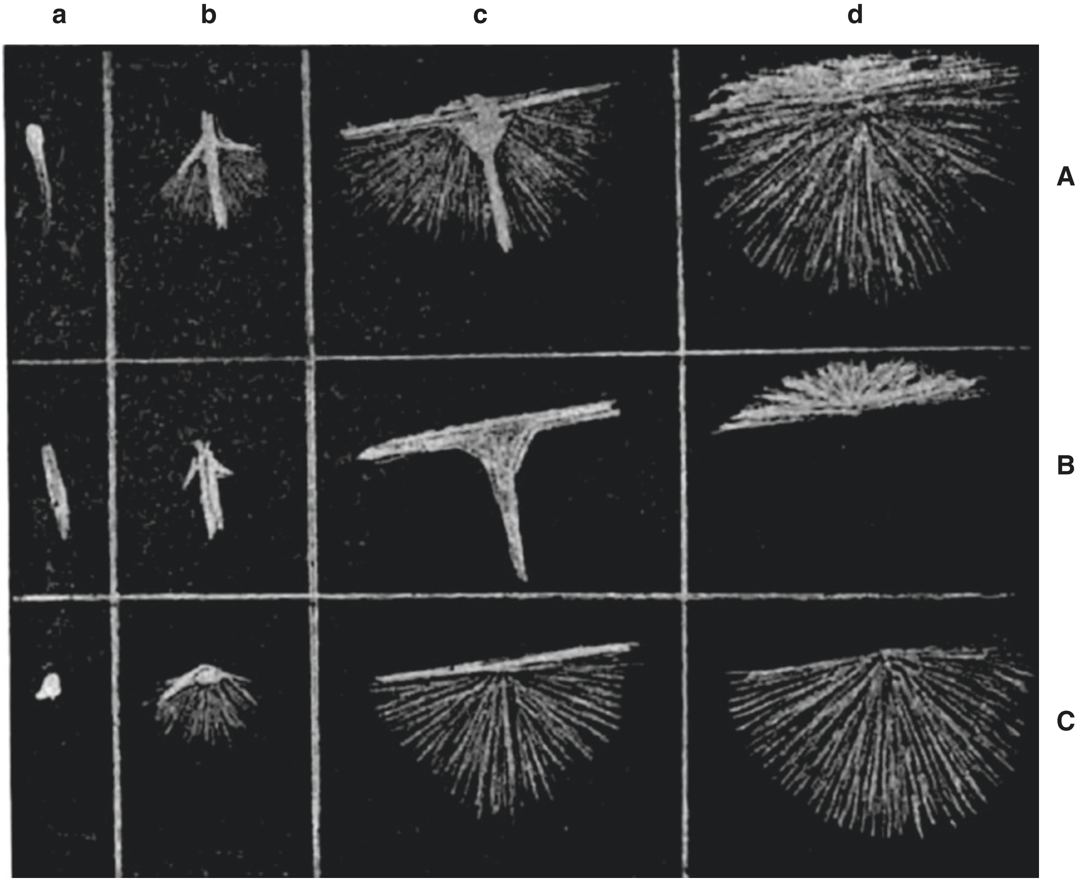


Fig. 42.23 Images of astigmatic blur spots for a light source at different distances comparing three conditions, e.g., uncovered pupil and covered upper and lower half (from Tscherning (1898), 141, Fig. 88)

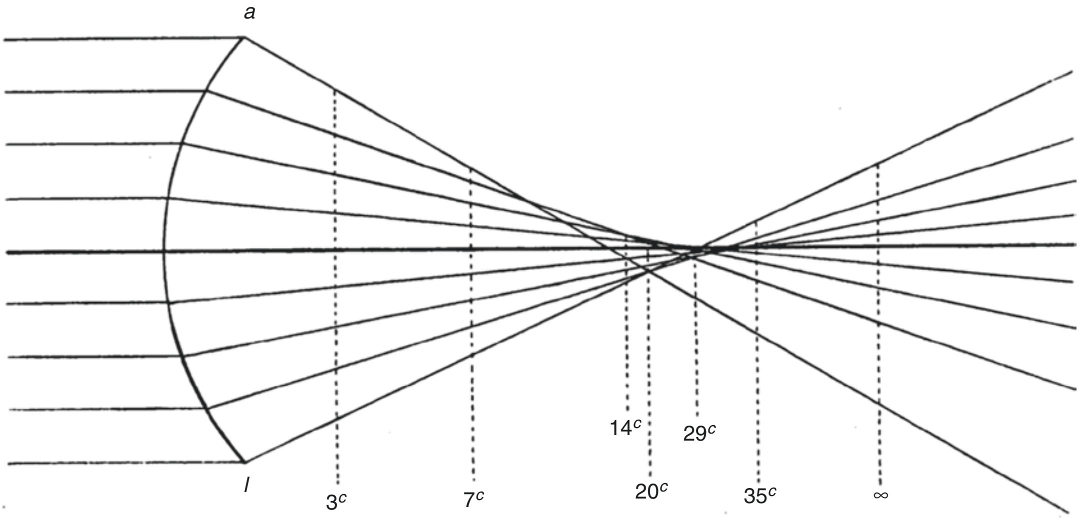


Fig. 42.24 Diagram of ray distribution as refracted by a lens with spherical aberration marking a number of distances along the tangent plane that will correspond to the different blur images (from Ove Müller Rée (1896), *Undersøgelser af Øjet med et Lysende Punkt*, 103, Fig. 8)

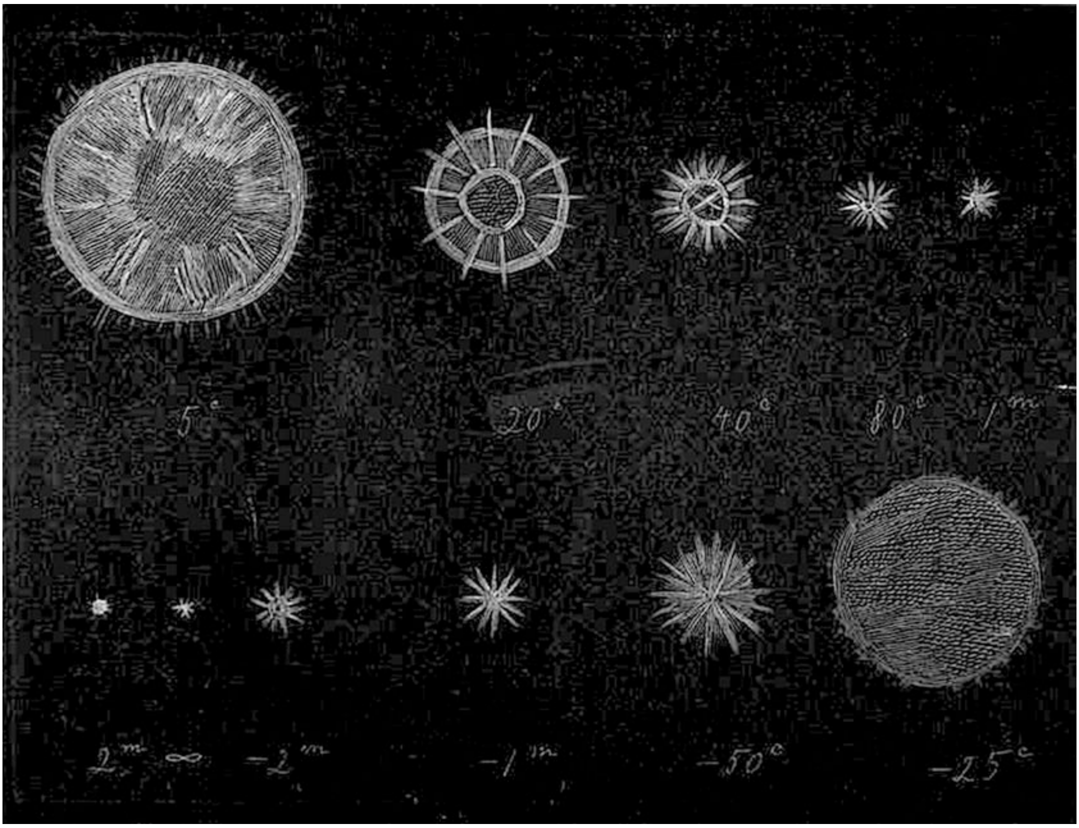


Fig. 42.25 Table of drawings of images of blur circles from a bright point source at different distances from a normal eye (from Ove Müller Rée (1896), 65, Table XVI)

focusing on to the focal axis before the perpendicular ones do) (Fig. 42.26).

The dissertation, submitted in late 1895, earned him a doctorate early in the following year. The examining committee included the physiologist Christian Bohr, father of the quantum physicist Niels Bohr ([97]: p. 208).

Tscherning borrowed several of those tables of images in a chapter on irregular astigmatism to illustrate also the variety of experiences even for single individuals, including Müller Rée and himself ([90]: Chap. 10) (e.g., Figs. 42.22, 42.23, 42.25, and 42.26). He used some of the same tables subsequently in his contribution to the *Encyclopédie Française d'Ophtalmologie* of 1904 [98].

In the 1898 treatise, the subjective images were preceded by a set of standard images with the idealized geometrical figures for regular astigmatic images of a bright source point—that is, Donders' visual catalog of distorted blur circles and focal lines. These set the optical standard that visualizes individual conditions and possible additional kinds of optical and non-optical contributions (Fig. 42.27).

Tscherning also reproduced drawings of entoptic phenomena from Helmholtz's *Handbuch* and from research by the Canadian ophthalmologist George J. Bull, who joined the Sorbonne laboratory in 1886 after teaching and practicing in Montreal and New York (Fig. 42.28).

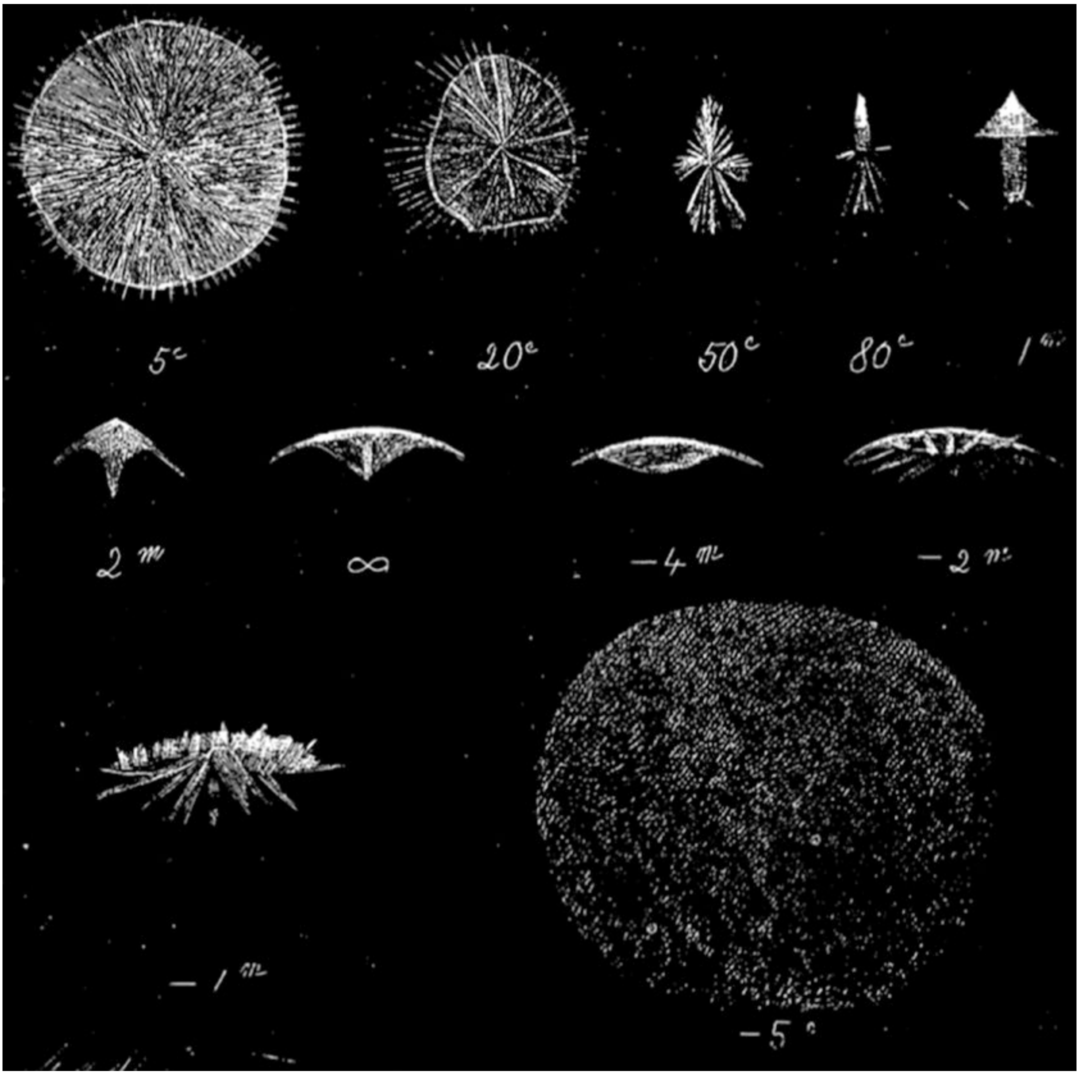


Fig. 42.26 Table of drawings of images of blur circles from a bright source perceived at different distances with Müller Rée's left eye, with oblique astigmatism (from Müller Rée (1896), 110, Table XXXXIII)

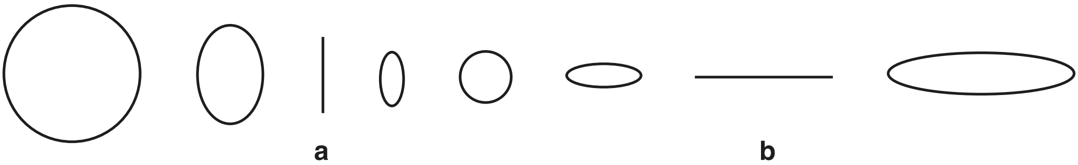


Fig. 42.27 Geometrical figures representing distortions of blur "circles" and focal lines in optical simulations of regular astigmatism (from Tscherning (1898), *Optique Physiologique*, 107. The image was adapted from one in Fick 1879, in Hermann's *Handbuch der Physiologie* v. 1, 109, as a simplification of the similar one in Donders (1864), see Fig. 42.16)

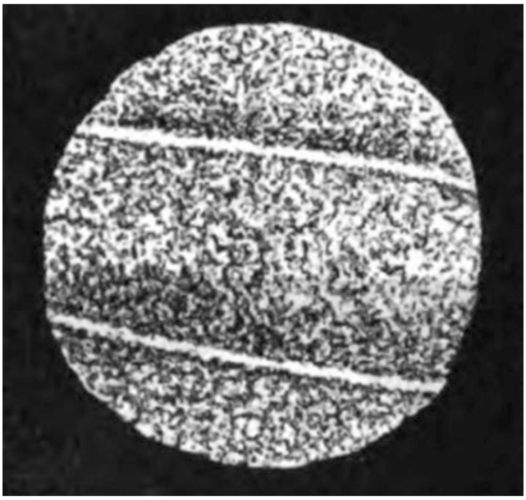


Fig. 42.28 Image by Bull of blur circle after blinking (From Tscherning (1898), 139, Fig. 97)

Bull would publish several more drawings in 1902 [99] (Fig. 42.29)

Notably, Bull incorporated a few photographs with optical simulations in 1896 [100] and Tscherning followed suit in 1900 (see below) and in the *Encyclopédie* discussion of optical aberrations of the eye—as did another contributor, David Émile Sulzer.

Using geometrical drawings or diagrams to illustrate visual phenomena was also consistent with the theoretical standpoint of geometrical optics, with a focus on geometrical notions and demonstrations involving hand-drawn graphic construction and illustration. The pictorial practice ran, in this sense, parallel to the pursuit of optical explanation: seeking a graphic mediation between the geometrical ideal, the intelligible and general explanatory elements of the theory, and descriptive phenomenological detail, the qualitative and particular phenomenal elements of visual experience. Four types of pictures, or graphic models, are involved in the depicition of visual phenomena, that is, in addition to sketches of anatomical details, instruments and diagrams of data (I have drawn attention to a total of seven types): subjective drawings–or free-hand drawings of the subjective image–, diagrams–ideal-

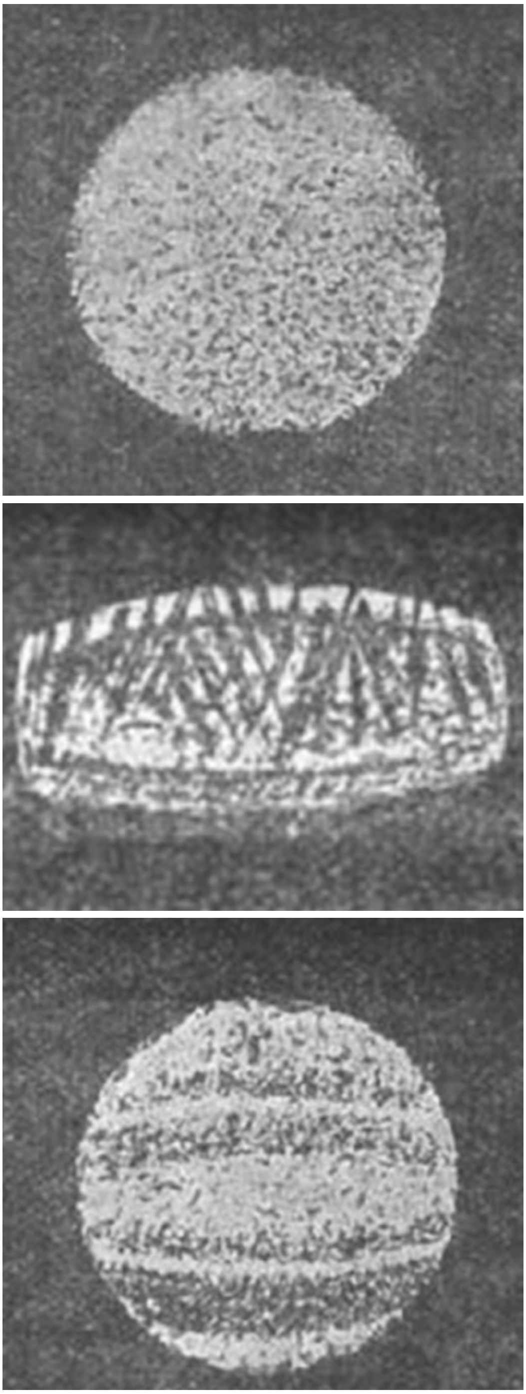


Fig. 42.29 Images of blur circles before, during and after blinking (From Bull (1902), "De l'asthénopie produite par le clignement," in *Bulletins et Mémoires de la Societé Française d'Ophtalmologie*, 19, 579–80, Figs. 1–3)

ized geometrical sketches–of the subjective drawings, diagrams of the geometrical optical phenomenon explaining the subjective image, and diagrams sketching the geometrical image resulting from the physical optical reproduction or simulation of the subjective image. They form a network of geometrical analogies intended to represent a subjective experience and its optical explanation.

The basic general geometrical concepts such as straight lines and relevant kinds of curves are often introduced in separate pictures. They establish the graphic elements standing for basic geometric modeling tools that will help represent and connect the behavior of light, the structure of optical systems from lenses to the eye, and the perceived images.

At the turn of the twentieth century, the Swedish Allvar Gullstrand adopted the analytic standard of mathematical physics and formulated a systematic mathematical treatment of visual sensations of monochromatic dioptric aberrations. It was based on the application of analytic geometry to systems of curves that he visualized in schematic diagrammatic pictorial models [101]. The goal was not simplicity and convenience of graphic reproduction (away from subjective depictions of more or less typical or representative individual experiences grounded not just on assumptions of generality of optical explanation but, at least, on subjective judgments of similarity and recognition). The framework provided a mathematical objective simulation (alongside physical optical ones), and not just objective material graphic reproductions. As Maxwell had applied analytic geometry to the empirical interpretation of differential equations of field physics, e.g., in terms of lines of force and tension in the ether, in this case Gullstrand referred to tensions and lines of force in the structure of the lens associated with the star-pattern of aberrated images, for instance, in his supplements to the third edition of Helmholtz's *Handbuch* ([102]: vol. 1, 362).

For the balancing and mediating job between the geometry of optical models and the geometry of visual experience, another picture has provided the graphic representation of the optical models for explanatory hypotheses. It comes in two corresponding types, the third and four listed above. The long-standing predominant type at the center of the project of optical explanation, since at least Kepler—I am not including Euclid's or Alberti's geometrical treatment of perspective—depicts the geometrical characteristics of the physical process of propagation and interactions that light undergoes in different optical setups, including an optical model of the eye (the schematic eye). It typically depicts a simple geometric source object such as a point source.

The second, minority type, is the picture portraying the optical image, normal or aberrated, that results from specific optical conditions, as depicted by the first type. It presents an idealized, schematic image with general value: its function is to subsume—by approximation and analogy—and to replace the images of particular subjective perceptions and to associate with them, in a visual argument, the general explanatory process depicted by the first type of image. Both constitute visual analogical models and illustrate optical models of vision. Early examples of the second type are Jurin's and Helmholtz's images of blur circles in the optical projections of point and lines sources, respectively (Figs. 42.4 and 42.30).

The second type can play also a distinctive demonstrative role as a result of its different analogical role. The first type, as just noted, provides a schematic geometrical model of different optical arrangements that, according to optical theory, explain different features of images, sharp or aberrated, projected on a screen and also on the retina. The hypothesis applied to the eye has the form of an analogical model and, more specifically, an analog simulation [103], in which the analogy is a (physical) causal similarity between the simulating process and the simulated process. The resulting demonstrative force, in the case of evidentiary support, is not, however, the conclusion of a mere argument by analogy. After Giambattista della Porta had suggested an anal-

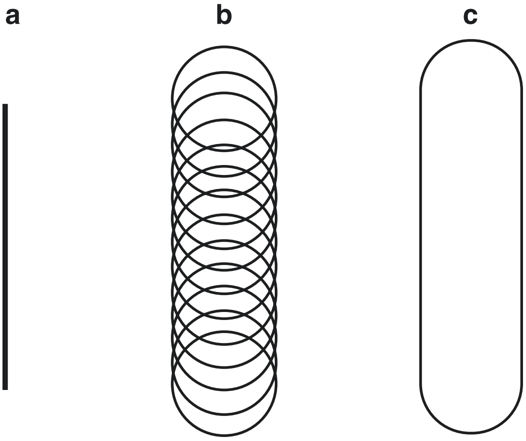


Fig. 42.30 Images of a blurred projection on a screen of a bright sharp line source also represented as a composition of blur circles (from Helmholtz (1867), *Handbuch*, vol. 1, 91, Fig. 47; reproduced in Helmholtz (1909/1924), vol. 1, 102/122, Fig. 53)

ogy between the eye and the camera obscura he had invented, Kepler, as noted in Sect. 42.3, identified the process of vision as a dioptric process: the optical process involving the refractive role of the crystalline lens in focusing optical images on the retina ([9]: vol. 1, p. 87, [104]: vol. 1, p. 116, [10]: vol. 1, pp. 96–7, [91]: p. 38). The successful use of spectacles, of lenses for the sake of improving vision, could be equally explained.

What provided the empirical support for extending the optical model to the case of the eye, that is, for representing the eye as an optical system? We can find three related kinds of demonstrations. The first involves analog simulations. Helmholtz referred to what he called "artificial models," or replicas (*Nachbildung*), of the eye ([9]: vol. 1, pp. 87, 102 and 141, [10]: vol. 1, pp. 116, 134 and 192) and "artificial imitation," according to which an optical arrangement could "demonstrate the principal phenomena of vision, the application of spectacles" ([9]: vol. 1, p. 87, [10]: vol. 1, p. 116). For the case of unaided, or uncorrected, vision, the demonstration required what we may call a reproductive experiment or experimental simulation, involving a physical optical process that resulted in enough recognizable similarity between the objectively projected optical images and the perceived images. For the case of corrected vision, the physical and functional connections of the optical aids to the eye and the process of vision contributed additional support to the hypothesis of a joint optical explanation—of a single optical system.

Helmholtz followed the presentation of his own example of the composition of blur circles explaining the blurred line with the claim that blurred "images of the same sort may be projected on the retina of the eye" ([10]: vol. 1, p. 122). Similarly, he referred to the demonstration of the optical cause of permanent "star-shaped, blurred" images by Fick's experimental simulation, in which "the effects may be imitated artificially by obtaining the image of a luminous point in a glass lens with a film of water on its surface" (p. 192).

The second kind of demonstration, whose first instance Helmholtz attributed to Christoph Scheiner, involved the demonstration of the optical properties of the structure of the crystalline lens and the vitreous humor of dissected animal and human eyes (ibid.). The third kind involves the artificial induction of visual aberrations, not corrections, by means of optical arrangements, with different kinds of lenses, separately or in combination; they were subsequently referred by Tscherning and others as "artificial" or "artificially induced" eye conditions.

Like the first kind of optical simulation—or "artificial imitation"—in order to have any explanatory relevance and credibility, the integrated eye-lens aberrating simulation required accepting enough optical similarity to natural cases of aberrated perception. The acceptance was prompted by the results of the second kind, the earlier empirical in vitro experimentation, by Scheiner and others, on the optical properties of eyes, especially the crystalline lens—hence its name.

In fact, there is also a fourth kind of simulation involved. The empirical support for the optical hypotheses depicted by images of the first type of artificial simulation, and thereby the explanatory success, relies then on the image resulting from performing the optical simulations and depicted by a second type of image, their graphic reproduction. This process of graphic imitation or simulation, a fourth kind, also involves a chain of representation or reproduction that includes the subjective image of the simulation. The resulting graphic depiction is a requirement for their public demonstrative role. They not only show the resulting optical image; they are also credited with simulating by analogical relation the subjective image, an image and an analogy that provide validation.

What about the role of validation? Here we find a second chain. The subjective images with the validating and calibrating roles are those experienced by the same subject but reported to someone else responsible for the drawing (especially with induced aberration) or, more typically, drawn by the same subject with sufficient eye-hand coordination. There does not seem to be any informative record of the drawing process. The same-subject drawing task requires that she can experience the equally subjective image in the drawing either with corrected vision or else to enjoy sufficient degree of acuity for the task of drawing effectively at a certain distance. In fact, the process included a key role for the eye also tracking the drawing process along with a personal sense of visual recognition—with or without a tacit consideration of similarity—and a public promise of relevant (intersubjective) similarity: this time without recognition, for lack of access to the original, subjective image. Note that the drawing task requires also reliable memory support through the process of alternating access to the subjective image of test source and the image in the drawing. Drawing is a complex cognitive process that in effect in the production also of the experimenter's graphic simulation.

The resulting general optical hypothesis, extended to visual phenomena, can be used to make further predictions, and the subsequent degree of matching could be used to provide further inductive support for the optical explanation (I revisit this point in Sect. 42.5).

It is therefore the analogical interpretation of the second type of image, the graphic reproduction of the image produced by the artificial simulation, sometimes shown alongside the subjective ones, that helps lend public credibility to the general optical hypothesis claimed to explain and identify an individual and a more general kind of visual experience, typically a kind of aberration, according to the model depicted in the first type of images. The graphic diversity present in the visual arguments about vision expressed a diversity of sources of authority on matters of representation and evidence: objective general simulations and subjective individual data. The chain of representation and explanation involves also two graphic simulations and two subjective images, the experimenter's subjective of the projected image in the optical simulation and the subject or patient's image of the test point source or test type. To complete the subject circle of perception, one could add the subjective image of the viewer/reader!

Talk of the distinction between subjective and objective methodology (for instance, [38]: pp. 134 and 210, [101]: p. 198, [102]: vol. 1, p. 421, [19]: pp. 350–51, [105]: pp. 44–5) also reflected the tension that pictorial analogies and logical arguments could hardly resolve. The underlying conflict between generality, or typicality, and individual difference raged on. Gullstrand objected to the use of lenses on participants to induce artificially aberrated visual experiences such as astigmatic star figures: "the method is subjective and dependent on the subject's powers of observation" and, as a consequence, "it is not adapted for use with a large number of subjects" ([102]: vol. 1, p. 421). On the same grounds, he objected also to Helmholtz's and Tscherning's drawings of their own visual experiences (pp. 423, 431, and 434); they present abnormalities, and, in Helmholtz's case, only some "are sufficiently typical to be used for demonstration" (p. 423).

The taxonomical project came gradually to an end along with the century and the prevalence of published, not used, graphic depictions of subjective sensations. A shift took place in their use alongside the rise in the use of photographs and new focus of research and education, theoretical and clinical, with new practical and methodological interests in objective modeling and evidence, and the production and publication and images. The new imagery and training emphasized the doctor's anatomical observations and guided anatomical interventions. Anatomical drawings were often still preferred for production and printing convenience to be used alongside first-hand clinical training [106].

By the end of the nineteenth century, a new type of picture, photographs of optical images, made its appearance seeking to replace subjective images and contribute new physical realism to earlier the graphic argument associating subjective images with optical explanations. The introduction of the photographic standard and practice depicting and explaining the experience of visual aberrations stood for both a different way of addressing the problem and a different failure to solve it. The photographic process could both produce and depict the images and get the status of objective model of both aspects of vision, for the purposes of demonstration as presentation and representation and demonstration as evidence. The subtleties and contingencies of pictorial evidence, or evidential reasoning with images, are many, and I will not address them here, except for a number of remarks in Sect. 42.5 [1, 2, 107–109].

The project of depicting blurred images and blurred vision seems to have followed a trajectory markedly different, for instance, from the one in Daston and Galison's history of pictorial objectivity. In their account, it is photography that introduced the more authentic and trustworthy picture of the world through the causal connection to actual particulars; whereas hand drawings had been aiming to be true to nature by means of some rare kind of subjective and artistic direct access to universals and archetypes. In the case of images of vision, it is the subjective drawings that had direct causal links and access to the diversity of particulars—in this case the relevant target was the individual subjective image.

Drawing it involved a complex, and potentially unreliable, causal process connecting some particular visual experience and the hand documenting it. Only more indirectly, relevant similarity to other images associated with similar optical conditions—and perhaps additional, optical, and anatomical, explanatory considerations—extended the documentary value of the hand-drawn picture from the particular to its alleged broader type.

By contrast, drawn objective images of the second type, graphic simulations of optical simulations or photographs of their results contribute more objective depictions of some particular optical image and, indirectly, its optical kind (the explanation). But their particular causal reach—their indexicality—extends only to the particular subjective image in the simulation as perceived by the individual drawing them. The drawing process is different, although, as noted above, it involves a mediating subjective image, the experimenter's. But this is not the ultimate target in a chain of representations in simulations. In relation to the subjective, perceived test image that the optical simulation ultimately targets, the graphic representation—the graphic simulation—can be only a generic and approximate analog, relying especially on a causal (optical) similarity in kind, as depicted by an image of the first type, and according to a previously established theoretical model with empirical support.

The subjective depictions of blur played several roles: (1) descriptive or taxonomical of the particular experiences of anomalous vision and of different conditions and different situations, also as illustrative instances of a type of more general validity; (2) potentially explanatory, by suggesting, analogically, the potential optical explanation of vision and its dysfunctions (i.e., the potentially accurate representation now of the cause or process of production of the subjective blurred image); (3) auxiliary tracking of evolution of corrective clinical interventions; and (4) evidentiary role—demonstrative role different from the illustrative one in (1) inductive support of three different but related practices and results, namely, diagnostic classification, potential explanation, and corrective clinical interventions.

Subjective images have continued to play a validating role for the analogical images produced by two more kinds of objective simulations, photographic simulations and computer simulations (coming into use in the 1890s and 1980s, respectively).

42.4.4 Photographic Simulations: From Demonstrating Classifying Categories and Explanations to Demonstrating Tests and Treatments

Photographic simulations of blurred vision, the fifth kind in my view, followed the use of images such as hand drawings and schematic geometric diagrams depicting optical simulations, images resulting from arrangements mostly of lenses, and diagrams considered analogous to the optical constitution of the eye and depicted accordingly in additional diagrams. With the invention of photography around 1839, in a turning point, the optical analogy was extended to photographic cameras and to the demonstration of other aspects and phenomena of vision: for instance, simulating and explaining binocular depth-perception with the lenticular stereoscope and stereoscopic photography—contributed by Brewster and the photographer Antoine Claudet, then Maxwell with the photographer Thomas Sutton, and discussed, for instance, by Helmholtz ([110]: Chap. 11, [10]: vol. 2, pp. 72, 173, 178, 229, vol. 3, pp. 285, 302–3, 312, 344, 359), Le Conte, Du Bois-Reymond, and Tscherning ([63]: pp. 37–8, 198, 213, 220, 236, 314 and 322). Immediately after came the demonstration of color vision, Maxwell applied stereoscopic models to illustrate Young's trichromatic theory [2, 11, 12].

While in 1841, the eye surgeon William Mackenzie had written of "the analogy of the eye to the camera obscura" ([111]: pp. 12–13). Helmholtz did attribute the analogy originally to de la Porta ([9]: vol. 1, p. 87, [10]: vol. 1, p. 116), and in 1856 Sutton noted, following Brewster, that "the human eye is a camera formed on the same principles" and that, like his own eye, the photographers direct his camera as he chooses and "his prepared plate or paper is its retina, and on that he fixes the impression, and brings it away with him" ([112], p. 33).

Next, I turn to a number of the cases that illustrate and support a complex understanding of photographic simulations and their uses. The analogy of the eye to the photographic camera provided the guidance required to carry out photographic simulations of vision and to record and reproduce the resulting images with the distinctive authority of photographic objectivity. On such grounds, the new images of blur could serve more effectively than their predecessors the purpose of demonstration—illustration and evidence—of ophthalmic concepts, models, and treatments. However, in the process, neither photographic nor computer simulations could fully replace earlier types of pictures. In addition, as in the use of external ophthalmic photographic images discussed above, their use and significance are often informed also by considerations of disanalogies between the photographic camera and the eye.

This photographic turning point in the visual depiction of blurred vision took place in Paris, in the early-1890s, with George Bull. I want to draw special attention to Bull's much neglected landmark article [100], because, to my knowledge, it uniquely introduces, illustrates, and describes new and different roles for photography and, even more uniquely, it explicitly articulates the practice, evaluation, and reasoning behind their methodological significance. Moreover, the new photographic standard, short of replacing Young's, included a new use for subjective drawings. While the publication of the photographic study immediately followed Tscherning and Müller Rée's use of drawings at the Sorbonne; after Young's graphic standard from almost a century earlier, the production of the photographs took place almost simultaneously, if not preceding them, starting in 1892–1893 (p. 201).

Bull sought to do with photographs what drawings couldn't do, in addition to what they could, namely, representing the visual effects of refractive error—the different distortions in visual images—and simultaneously demonstrating its causes. For Bull the benefits were both explanatory and practical, especially in relation to patients' loss of visual acuity.

As Bull introduced it, he attributed a representational function to both photographs and the photographic process. It consists in *representing* aberrated vision such as myopia, hypermetropia and, especially, astigmatism, and *recording* some of its aspects by *reproducing* pictures of standardized test-types and other figures "as they would be seen by patients suffering from given errors of refraction" (p. 200; I italicize his own terms). He also called this function photographic *imitation* (pp. 246–47) and photographic *simulation* (p. 207). For the main characteristic of the deformed images or vision, Bull added to the canonical term "indistinct" the terms "blur," "blurred," and "blurring"—as also Morton had done in his textbook [113].

In another sense of demonstration, Bull attributed to the production of the photographic images also theoretical—explanatory—and evidentiary roles. The former, in Bull's town terms, consists in *answering questions* ([100]: p. 216), or *clearing up* issues (p. 247), that is, providing explanatory hypotheses, while the latter consists in *showing* the superior value, for instance, of testing techniques (ibid., 216) and in *constituting proof* of general laws (p. 244). The exploratory processes that performed such theoretical and evidentiary roles Bull called *photographic experiments* (p. 247). Arguably, then, Bull introduced the photographic methodology. Because the use of test-types to determine visual acuity provided a bridge between the laboratory and the consulting room, between exploration and correction, Bull, researcher and clinician, also claimed for his methodology and his results a dual significance, "theoretical interest and practical value" (p. 201).

The process of photographic production was guided by the long-established explanations with optical models of sharp, deformation-free vision and of its known aberrations. Such models supported the conception of blurred vision as refractive error. From the same standpoint, Bull's photographs are, unlike the drawings, analog simulations, that is, based on distinctively similar causal or physical processes [103]. To reproduce and thereby represent myopic and hyperopic vision, Bull simply adapted the optical features of the photographic system—composed of camera aperture, objective lens, and sensitized plate—by placing the plate out of focus ([100]: p. 200) (Fig. 42.31).

For the less-settled case of astigmatism, his main interest, Bull followed the more recent research by Helmholtz, Donders, and Tscherning and, with his assisting technician, placed the objective lens in an inclined position (p. 201). They also experimented with added spherical and cylindrical lenses in order to reproduce different astigmatic conditions and different degrees of refractive errors in diopters (and reduced visual acuity) (Fig. 42.32).

The roles of representation and of suggestion and support for explanations are inseparable; the latter relying on the former; and for these purposes, the case of astigmatic vision is indirectly supported by the corresponding successes in the cases of myopia and hyperopia. All the successes, however, depend on three kinds of analogies: (1) relevant optical (physical and geometrical) analogies between the processes of photography and vision; (2) between the respective structures involved in the optical function; and, central to Bull's methodology, (3) the relevant visual analogy between the photographic images and the subjective images.

The third kind of analogy is a matter of multiple possible respects and degrees and concerns, in particular, inseparable features such as geometrical shapes and density and distribution of brightness. Judgments of analogy or disanalogy, while framed in those terms, also appear in terms of correspondence and match. But, whose match? Whose recognition, possibly, but not necessarily, including an explicit recognition of similarities that spells out and prompts such comprehensive, black-boxed recognition? What vision refractive status? And with whose and what images?

To test the photographic images by comparison, Bull relied on two kinds of sources of refractive error: eyes with a natural, uncorrected, condition (including his own), and eyes with the much preferred, so-called artificial abnormality, a refractive status artificially induced by means of a lens or combination of lenses—on "normal" eyes, with high acuity and known low aberration—(p. 205). Artificially abnormal eyes offered

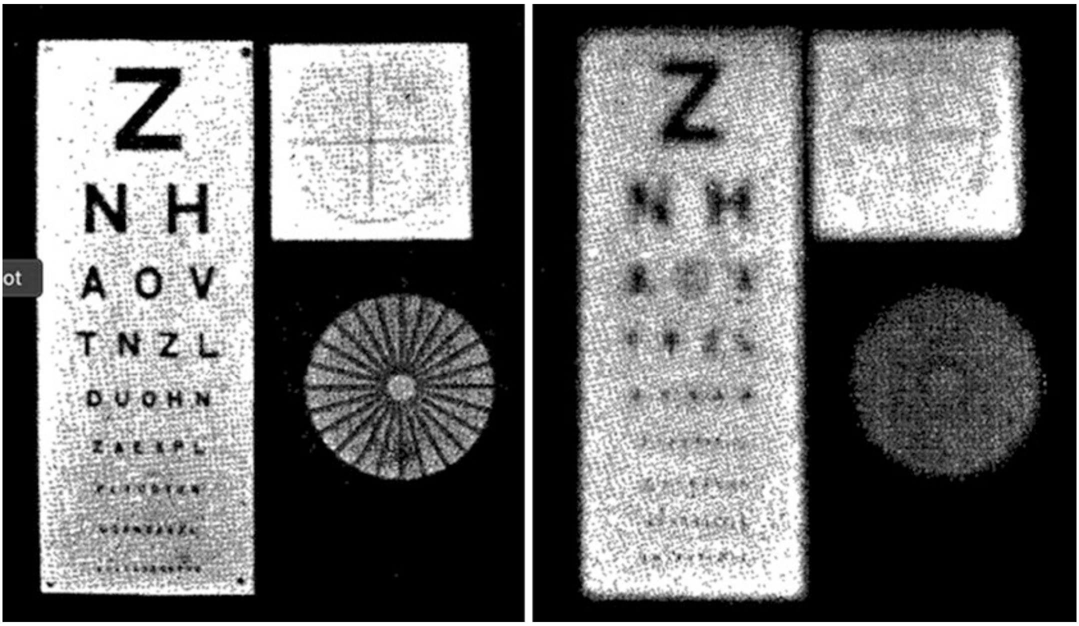
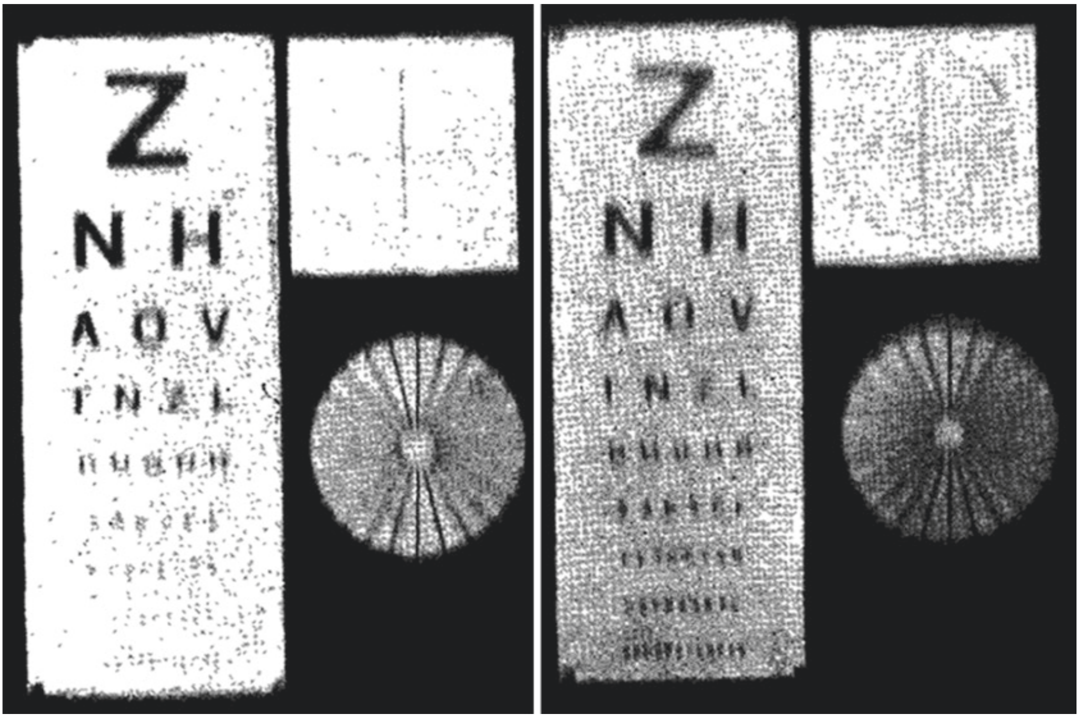


Fig. 42.31 Photographic simulation of myopic vision with 0.25 and 0.75 diopters (from Bull (1896), “Visual effects of refractive error,” *Trans. Ophthalmological Society of the United Kingdom* 16, 209, Figs. 24, and 213, Fig. 26)



Error 0 + 1.

Error 0 – 1.

Fig. 42.32 Photographic simulation of direct (vertical) myopic and hyperopic astigmatism with 1 diopter (from Bull (1896), 215, Fig. 28) methodological advantages. The resulting enhanced control over the degree of refractive error facilitated the accuracy, reproducibility, and diversity of comparisons, then and now. In addition, the shared optical system, the artificial lenses, extended the natural optical system in such a physically commensurable way that facilitated the analogical application to eye vision of the optical explanation in terms of conditions materialized in the camera and the photographic process. The subtle issue here is whether the significance of the result, an uncertain inductive conclusion, begged the question or involved any circularity, that is, it applied and tested the optical explanation to the eye by literally planting the evidence, the optical simulation, in the form of artificially induced aberration. Notice, however, that the procedure assumed the optical functionality of the eye, and on that mode, the added lenses responsible for the artificial aberration did not replace the eye's own optical system.

Now, when Bull reported testing the photographs against an artificially abnormal eye or with the appearances observed by such an eye (ibid.), he was relying on images resulting from kinds and degrees of refractive error similar to the camera's. But, which images? The test comparison involved two kinds of images, one product of the optics of the camera and the other product of the aberrated optics of a human eye. For the photographic process, he was relying on the photographic image that could be observed by himself and by the study subject. Both observations, by himself and, if different, another participant, subjected to the conditions of artificial aberration, were obviously subjective, as all perception takes place inescapably within what I call the subjectivity circle. Still, they are both of the image on the same photographic picture, as materially and publicly available with the baseline refractive status, whether natural or corrected, shared by Bull and the test participant allowing both to assess the match—that is, they were using what we may declare, at least in those senses, an objective image.

What about the second image, separately produced and perceived by the optics of the patient's eye? This is the one that plays the roles of calibration and validation, the function of empirically testing the explanatory optical hypothesis enacted by the photographic process. For this matching image of the same test-type letters or same system of lines to locate the eye's principal meridians—the cross used by Donders and the fan-shaped chart after the Scheiner disc—(Figs. 42.31 and 42.32), Bull was relying indirectly on the patient's subjective image, that is, the appearance accessible only to the abnormal eye. But, how could then Bull, and not the patient, make the comparison himself, as he reports it (ibid.), and assess the degree of similarity or correctness of the match between the image produced by the camera and the one produced by the aberrated eye? For this he had to rely on two more direct representations of the subjective image. One representation, familiar from the clinical task of subjective refraction discussed in earlier sections, is the patient's verbal description, always liable to miscommunication (see Sect. 42.2). The more reliable alternative is the subjective drawing, which the patient has to recognize, in yet another required matching exercise and in the unaberrated conditions (i.e., at least for the functional performance of the task of drawing the image; it could be a matter of distance) shared with Bull, as a reliable objective picture of his private image. The photographic method replaces in representational function the drawing, but it does not eliminate its use.

Bull's application of his methodology for photographic experimentation is as instructive and exemplary as its design. The representational and evidentiary values of the photographic images require their correctness, a matter of analogy or approximate match. His results, however, showed both "a great likeness and a remarkable difference between the photographic and the visual resolution of an image" (p. 229). And, rather than an indictment of the method and the photographic analogy, Bull took the discrepancy as a challenge for the explanatory optical model replicated by the camera and a methodological challenge to explore the optical analogy further.

The successful matches for the reproductions of myopia, hyperopia, and astigmatism up to 1 diopter prompted Bull to address the issue of the influence of myopic astigmatism on reading acuity. For Bull the question could be put to what he calls the *photographic test*. The examination of the photographs discriminated between the lower impact of direct astigmatism and the greater impact of inverse astigmatism (p. 216). Bull's explanation is that the blurring of vertical lines interferes with the prominent role of vertical lines in reading letters. With the hypothesis, Bull made the assumption of a general relation between blur and monocular polyopia, which Bull supported separately, effectively following Helmholtz: "the presence of multiple images is the common law of all cases where, from whatever cause, the object is somewhat out of focus" (p. 204).

In fact, Bull contributed, based on the evidence from photographic simulations, two interconnected theoretical explanations of monocular polyopia associated with astigmatism. The methodological twist consists in how they are prompted, rather than by similarity, by difference, or mismatch. The first mismatch Bull drew attention to is between the superior acuity of the aberrated eye in recognizing letters on the test-type chart and the "acuity" of the camera that renders the same letters in the photograph hardly recognizable to the unaberrated—or corrected—eye (p. 205). Bull explained the difference in terms of additional optical processes of image production involving unconscious habits of vision such as different forms of orientation of the eye or head, blinking and accommodation that provide the viewer with an extended collection of images with "varying, and yet analogous deformations" (p. 206). The comparison of the multiplied images starts in the subject's mind "a chain of inferences" that leads to a correct identification, or categorization, of the letter type (p. 207).

Next, Bull proceeded to put to the photographic test the question of sources of acuity more specific to the astigmatic eye. He proposed three competing hypotheses: (1) focusing on the mean point between the focus of the principal meridians (the circle of least confusion), (2) focusing preferentially on one set of lines, and (3) superimposing multiple pictures in rapid alternation (p. 226). He introduced a methodological novelty in the photographic simulation of superposition by alternate focusing. It consists in the superposition of exposures resulting in what he called a photographic composite. The superposed or composite picture matched best with patients' descriptions and supported the hypothesis that could explain best the superior acuity of the eye revealed in the previous mismatch.

Finally, the recurring role of multiplication of images prompted Bull to submit to the photographic test what he called the theory of circles of diffusion or circular deformation (p. 229). From his acquaintance with earlier work by Helmholtz, Donders, and Tscherning, he would have been already aware of the diversity of astigmatic deformations of the diffusion field or blurred images of a single bright point. But, and this is for him the greatest and most telling difference between the eye and the camera, the astigmatic camera eye showed no polyopia, at least without the conditions of simulation of alternate focusing (pp. 206–7). In the footsteps of Helmholtz and Donders, he reduced the blur of geometrical figures to that of the bright point he called a star by showing the matching changes reproduced in patients' drawings (Figs. 42.33 and 42.34).

As a general optical explanation of blur, including polyopia, Blur proposed a hypothesis that guides the optical conditions of photographic simulation and submits it to its test. The general hypothesis aims to explain the fundamental blur star as common inhomogeneity in the structure of the crystalline lens; this contributes to the optical explanation of the visual effects of astigmatism (Donders had included a discussion of the role of a fibrous structure dividing the crystalline lens into sectors ([38]: pp. 546 and 549)). The camera, properly modified, would then provide "a very satisfactory proof" of "the law of the visual effects of all refractive error," namely, that they are "the result of the formation of different images by different sectors of the lens" ([100]: p. 244). The photographic simulation involved a lens split into three equal sectors and yielded an image of polyopia Bull deems "very closely analogous" to drawings made by his observers (p. 245) (Figs. 42.35 and 42.36). The close match

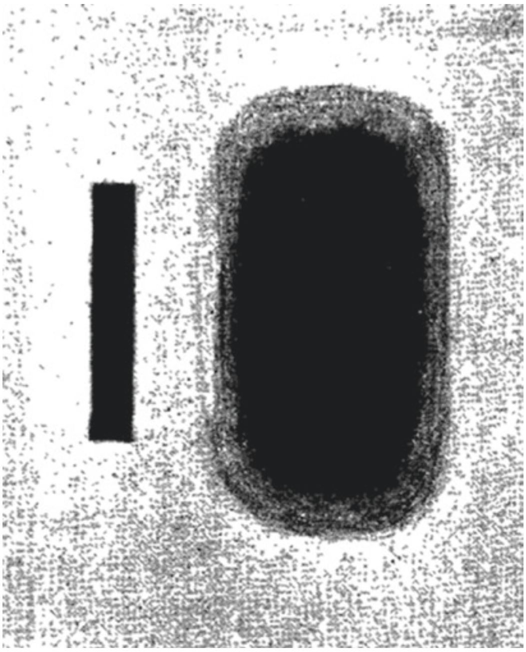
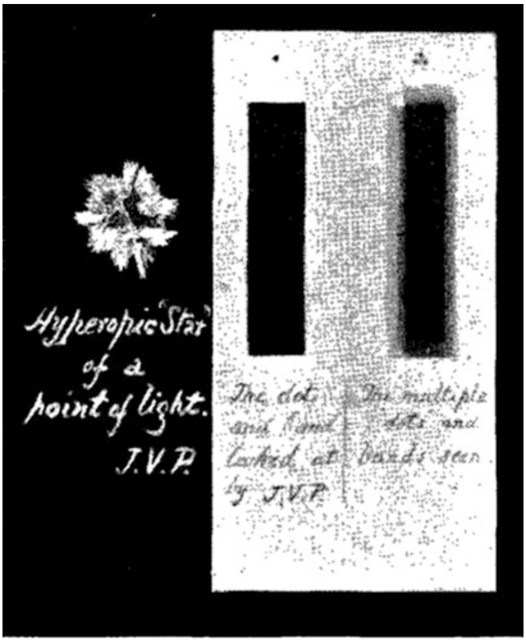

Normal image. Blurred image.

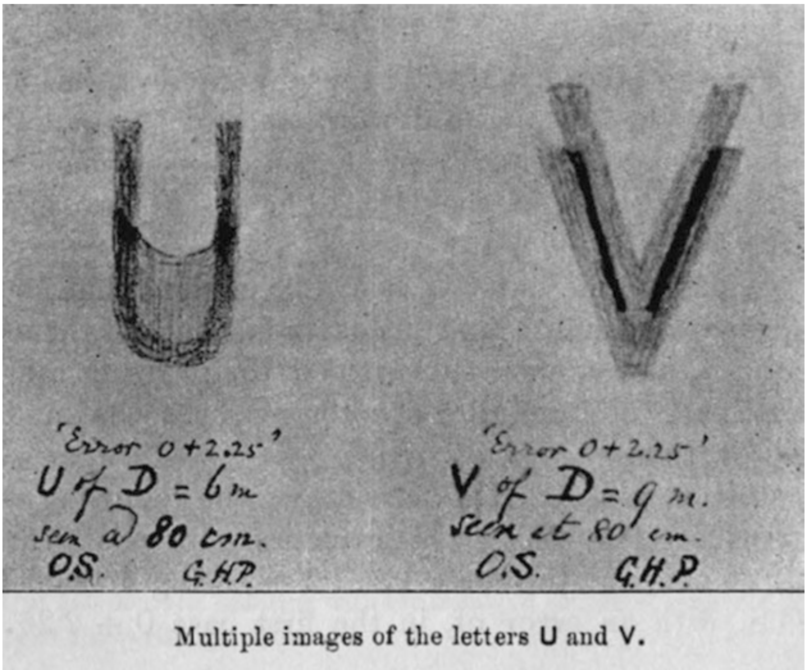
Fig. 42.33 Contrast between the normal and blurred images of a bar in patient's drawing (from Bull (1896), 230, Fig. 35)



Normal object. Multiple image.

Fig. 42.34 Concomitant match between normal images of a point and a bar and between their blurred images in patient's drawing (from Bull (1896), 235, Fig. 37)

Fig. 42.35 Drawing of astigmatic multiple images of letters (from Bull (1896), 240, Fig. 43)



Multiple images of the letters U and V.

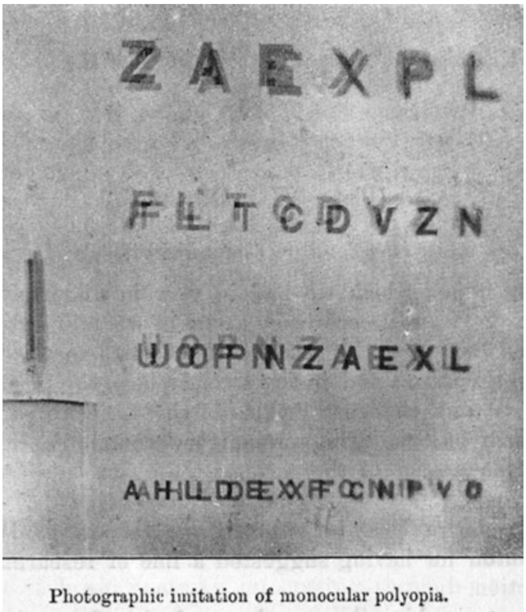

Photographic imitation of monocular polyopia.

Fig. 42.36 Photographic image, "photographic imitation," of letters according to monocular polyopia with lens split in sectors (from Bull (1896), 247, Fig. 49)

in this result of the photographic experiment, Bull declared, established satisfactorily the structural explanation of polyopia.

Bull's experiments might not have established his explanatory hypotheses, but they did establish a method of *photographic experiments* by means of *photographic simulation* or *photographic imitation* for portraying visual effects of refractive error and for exploring, suggesting, and testing hypotheses explaining them.

The novel experimental method allowed for the possibility of challenges to Bull's own results and conclusions. The camera, not just the eye, was an optical laboratory, and while the demonstration of an optical explanation for a resulting image constituted evidence in favor of its role in the production of similar images in the eye, the resulting image might be compatible with alternative optical processes. Thus, 4 years after its publication, the Boston doctor Frederick Herman Verhoeff rejected Bull's explanation of diplopia by producing photographic simulations of astigmatic diplopia without introducing any divided lens in the camera [114] (Fig. 42.37).

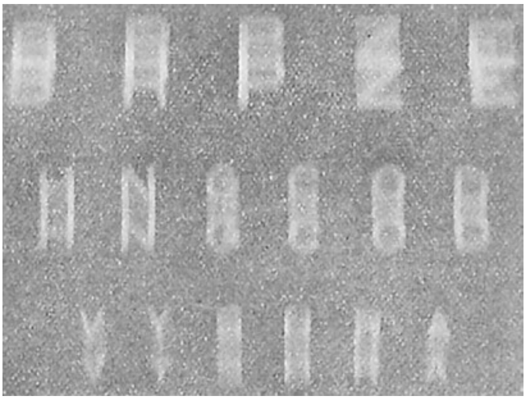


Fig. 42.37 Photographic simulation of astigmatic diplopia in hypermetropic conditions (from Verhoeff (1900), "The cause of a special form of monocular diplopia," *Archives of Ophthalmology* 19, n. 6, 568, Fig. 1)

He argued, accordingly, that spherical aberration alone could weakly induce myopic diplopia near the center of the crystalline lens—most visible through a so-called stenopaic slit—and could induce hypermetropic diplopia more strongly around the periphery (p. 471). In addition, Verhoeff failed to find any independent evidence of the divisions in the lens, also arguing that as a source of diplopia, the divided lens would impair visual acuity as well as the visibility of diplopia (p. 572).

At the IX International Congress of Ophthalmology in Utrecht in 1899, two of Bull's Paris colleagues, Tscherning and the fellow eye doctor François Oswalt, took the new standard of photographic exploration, explanation, and evidence center stage [115]. In an earlier book on eyeglasses and in a recent treatise on optical physiology, Bull and Tscherning had briefly discussed the corrective value of so-called periscopic or meniscus lenses, first introduced by Henry Wollaston in 1803 ([116]: pp. 19–22, [90]: p. 127). They improved peripheral vision by reducing astigmatic distortion and, through the first half of the nineteenth century, led to popular developments of wide-angular camera lenses for portrait and landscape photography, with the additional benefit of shortening exposure times.

Ostwalt shared Bull's practical interest in a more exact, scientific understanding of the astigmatic action of different shapes and degrees of curvature of periscopic lenses. In an article published in German in 1898 and reedited as a book in French the year of the International Congress, Ostwalt presented numerous tables and graphs—different kinds of pictorial aids—with quantitative empirical evidence supporting the corrective value of concave meniscus lenses in the role of divergent lenses. In the same text, in which he cited both Bull's book and Tscherning's edition of Young's works, Ostwalt also suggested that, for convergent lenses, only highly curved meniscus lenses provided any significant benefit [117]. Then, in the presentation at the International Congress, he lamented that his evidence applied only to divergent lenses and he added, in a notable twist, that "the demonstration was purely subjective" ([19]: p. 351, [105]: p. 44) and that what was missing was an "objective demonstration" ([19]: p. 350, [105]: p. 44).

What constituted the objective demonstration was precisely the production of a series of photographic images of clinical test-types and radial meridian lines of the fan-shaped chart with a camera that "imitated" the conditions of the lenses in front of the eye ([19]: p. 352, [105]: pp. 44–5) (Fig. 42.38). The evidentiary relied on a comparative evaluation of the images. The photographs were shown at the Congress meeting but were not published with the text in the Congress proceedings; they were published in a German version that appeared as a follow-up to the previous article on periscopic lenses, along with additional graphs and tables ([105]: Plate III, Figs. 42.1 and 42.2). Oswalt's choice of photographing charts reflected his clinical interest and contrasted with Tscherning's choice and research priority. For Ostwalt the primary value of the photographic demonstration was not theoretical but practical, supporting the clinical value of a corrective treatment—although his research was guided by mathematical optical models of the astigmatic effects [117]. It was also methodological: The camera stood for objectivity.

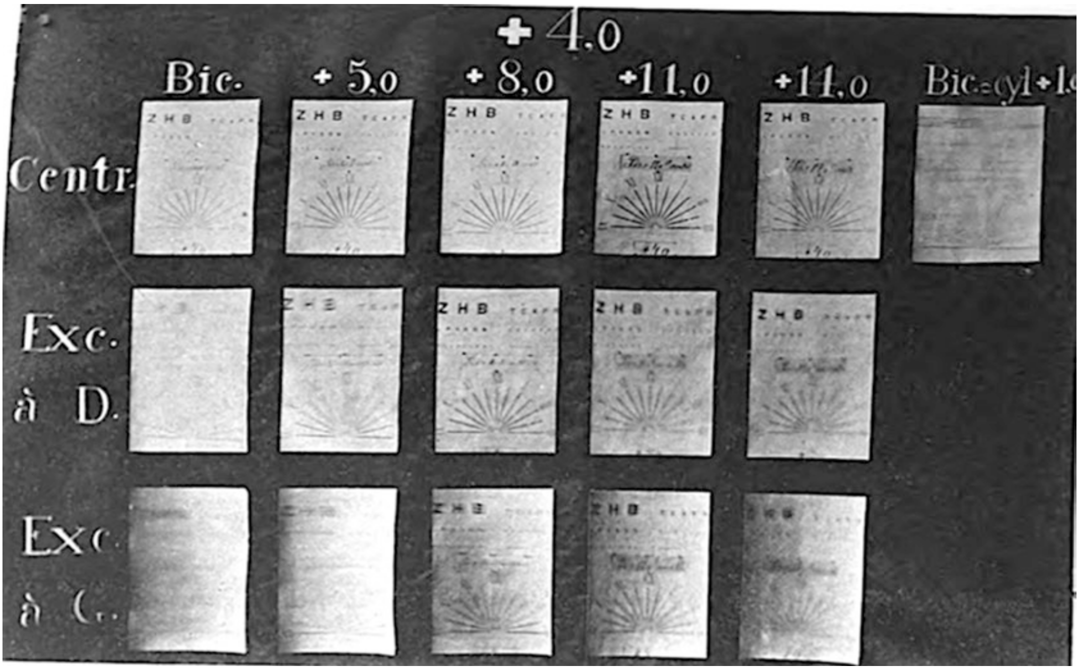


Fig. 42.38 Photographic reproduction of astigmatic action of convex periscopic lenses (from Ostwalt (1900b) "Weitere experimentelle Untersuchungen über die periskopischen Gläser," in *Albrecht von Graefe's Archiv für Ophthalmologie* 50, n. 1, Plate III, Fig. 2)

We can distinguish, then, the emergence of different roles for photographic images, as well as for images in general and of images of blur in particular. The roles are *illustrative* (representational by illustration) and *evidentiary*; but the evidentiary value, tied to the relevant physical similarity of the demonstrative process, may be either diagnostic (empirical, classificatory), explanatory (theoretical), or corrective (clinical or practical), that is, it may involve either evidence for the accuracy of a description or a connected physical explanation or evidence for the reliability of a corrective procedure. Of course, as Bull's example shows, the three evidentiary roles may be considered connected and defended jointly, a more correct specific optical explanation, not just guiding, general empirical results, suggested the possibility of a more reliable treatment.

Also on the issue of the astigmatic power of meniscus lenses, Tscherning adopted the photographic standard and the clinical goal. Following Ostwalt's intervention, he introduced ongoing research at the Sorbonne seeking to solve the problem of identifying the role of the possible curvatures of the two surfaces of meniscus lenses in eliminating the blur and distorted orthoscopic effects of astigmatism—the caustic surface—on peripheral vision ([118]: p. 360). The measure of distortion was relative to the image of a rectangular grid in paper inspired by his own aberrometer. As he had done with the reproduction of hand-drawn illustrations, each photographic image was juxtaposed to the geometric rendition of the shape of a type of lens in front of a diagram with a schematic eye (Fig. 42.39). The method consisted in matching a photographic image against the normal unaberrated image, noting the following disanalogy between the eye and the camera: that testing to improve photographic objectives offered possibilities that were incompatible with the eye structure (p. 359).

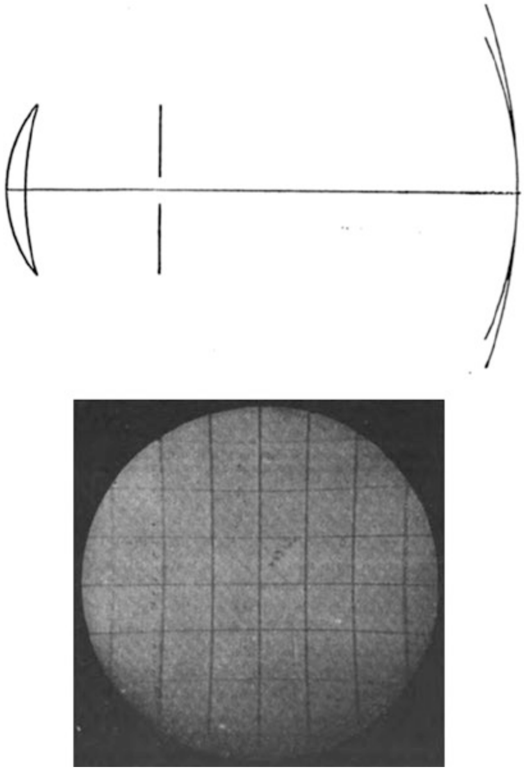


Fig. 42.39 Photographic reproduction of the sharpness and peripheral distortion caused by a meniscus lens, which Tscherning considered far superior to the biconvex lens and to the plain-convex lens (from Tscherning (1900b), Discussion of Ostwalt's "Recherches expérimentales sur le verres périscopiques," in M. Straub (1900), *IX Congrès Internationale d'Ophtalmologie d'Utrecht du 14 au 18 d'Août 1899, Compte-Rendu*, 363, Fig. 3)

By the turn of the twentieth century, the photographic turn in the study of aberrated vision had taken place, especially in France. In the new *Encyclopédie Française d'Ophtalmologie* [119], Tscherning and the Paris eye doctor David Sulzer, two of the authors in volume 3, alongside André Broca and Javal, introduced photographic simulations in their respective discussions of astigmatism. The photographs demonstrated, and not just illustrated, optical explanations in ways drawings could not. Sulzer showed the influence of astigmatic diopters and pupil diameter on blur and deformation of geometric types (pp. 428–30), while Tscherning, reproducing much of the material from his own treatise, supplemented the reproduction of subjective images of drawings from Young and Müller Rée series of diffusion spots with matching photographic simulations—geometrically simpler and more regular—demonstrating the credibility of the drawn images and of their optical explanation ([98]: pp. 166–207) (Fig. 42.40).

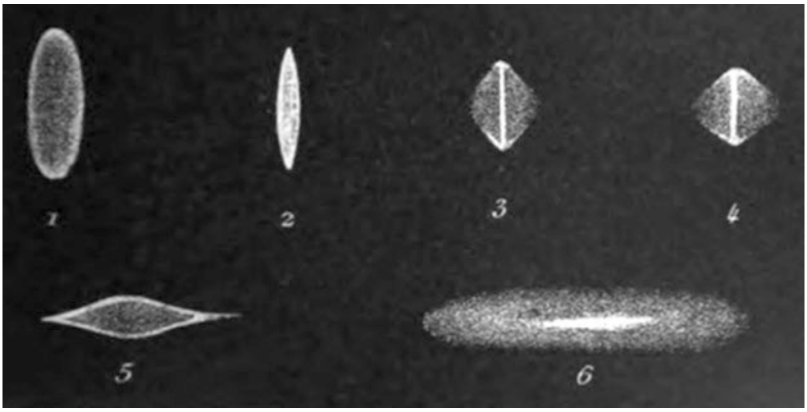


Fig. 42.40 Photographic simulations of diffusion spots associated with astigmatic vision matching one of the series of drawings by Ove Müller Rée also reproduced by Tscherning (from Tscherning (1904), "Dioptrique Oculaire," in Lagrange and Velude, eds. (1904) *Encyclopédie Française d'Ophtalmologie*, vol. 3, 199, Fig. 186)

After two decades with critical eyes on Tscherning's work on astigmatism, the Swedish ophthalmologist Allvar Gullstrand replicated the results of one of Tscherning's photographic simulations (Fig. 42.37). He reproduced the photograph in a supplement on monochromatic aberrations to the third edition of Helmholtz's ophthalmological canon, the *Handbuch* ([102]: p. 369, Fig. 146) (Fig. 42.41).

In the spirit of the point-source approach to investigating refraction errors, which he called subjective stigmatoscopy, Gullstrand noted the geometrical similarity of the cross sections of the caustic surfaces perceived in astigmatic vision, which he had verified for cases of artificially astigmatic eyes (p. 369). He noted the similarity also to features in some of Tscherning's drawings in the *Encyclopédie Française*.

Gullstrand had written his doctoral thesis in 1890 on the mathematical theory of astigmatism as a special case of a general higher-order mathematical theory of wavefronts and the complex geometry of cross sections of ray bundles in the tradition of Hamilton, Sturm, and Abbe. It was in the spirit of a scientific ophthalmology based on the models and techniques of mathematical physics, shared with Bull, Ostwalt, and the Sorbonne school, that he had turned to precision measurement, objective methods, and instruments of observation and photography—with publications such as *Objektive Differential-diagnostik und photographische Abbildung von Augenmuskellähmungen* (The objective differential diagnosis and photographic illustration of disabilities of the eye muscles) (1892) and the ground-breaking *Photographisch-ophthalmometrische und klinische Untersuchungen über die Hornhautrefraktion Objektive* (Photographic-ophthalmometric and clinical investigations of corneal refractions) (1896). His own reflex-free ophthalmoscope joined the developments of improved fundus photography initiated by Thorner [120]. For his contributions to ophthalmology, in 1911 Gullstrand received a Nobel Prize, still the only one awarded in ophthalmology.

Gullstrand's and Tscherning's commitment to photographic methodology and to its particular use in the study of blurred vision reflects the relatively late photographic turn in ophthalmology and optometry, in the footsteps of other scientific applications. While selective and inconsistent, the adoption of the technology was, in general, a matter of aligning shifting opportunities, challenges, interests, and standards.

Early challenges stemmed from required long exposures and wet collodion photographic plates that had to be prepared and developed on site, whereas in vivo eye photography, fleeting phenomena and anatomical access required

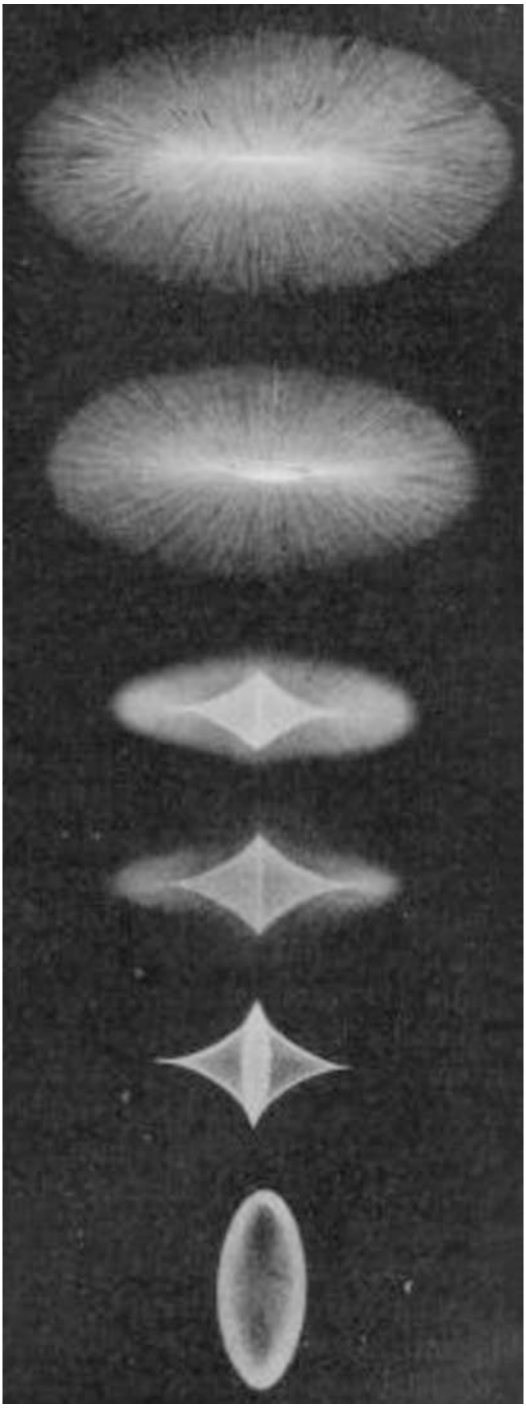


Fig. 42.41 Photographic simulations of diffusion spots in astigmatic vision, from Gullstrand (1909), "Monochromatic aberrations of the eye," in Helmholtz's *Handbuch*, third edition, vol. 1, 369, Fig. 146

relatively shorter exposures. Along with lenses allowing for shorter exposure, it was not until the 1870s that the user-friendlier gelatin dry-plate process appeared. In eye-fundus photography, for instance, there was the additional challenge of corneal reflex addressed by Thorner in 1903 and especially Gullstrand himself with his reflex-free ophthalmoscope of 1911 (ibid.).

For the case of optical simulations of blurred vision, the timing, relatively unconstraint by the length of photographic exposure, seems primarily linked to the timing of new interest in the richness of astigmatic phenomena and to the opportunities for classifying them and for demonstrating their optical explanations. Such projects relied on the prior production of documenting drawings, not only after the model of earlier anatomical drawings and atlases from the 1850s by Jäger and others but on account of their illustrative and distinctive evidentiary roles. The drawings, as already noted, would guide the photographic simulations, as would, also in external anatomical photography, the rising commitment to ideals of objectivity, contraposed to the distinctive but elusive and unscientific subjectivity of visual phenomena.

Pictorial standards and resources were, and still are, considered central to the rhetoric of communication and to the methodology of empirical exploration and correction of aberrated vision. As elsewhere in the sciences, the adoption of photographs and drawings and their joint use have, to this day, responded to views about their respective so-called epistemic power of representation and the related methodological power of demonstration—that is, aside of contextual considerations, for instance, material, practical, and cultural [121]. It has also remained controversial whether any such power is uniquely distinctive, and, if exclusive, whether it can be traced to its unique pictorial type, that is, whether it can be determined that a picture is the product of photography or drawing or some other imaging process according to some classification into pure pictorial kinds.

Neither a purist pictorial classification nor the corresponding attribution of exclusive uses and powers—values, functions, or roles—agrees with the historical, contextual, and plural character of pictorial practices, or even of pictorial ideology. Neither before nor after the invention of photography has the use of drawings been exclusively associated with human intention, anatomy, artistic values of creativity and appreciation or epistemic value of representation—for instance, under the standard of truth to nature and with the aim of tracking types rather than individuals [4]. Similarly, since very early on, not only did photography—drawing by light—follow artistic practices, but its scientific and non-scientific epistemic values, its anchor in particulars, and its alleged distinctive sharpness and objectivity were often opposed to the artistic qualities associated with hand-drawing and painting [2, 83].

Digital photography and image processing have further challenged the general or normative validity of the standard of photography based on optical-chemical recording, fixing, and display. Storage and display may not involve printing. In fact, in ophthalmological and optometric experiments, the digital on-screen flat display is sometimes criticized for introducing so-called moiré distortions or insufficient resolution or for failing to replicate the statistical richness of natural images with multiple point sources at different distances (see above; Kollbaum and colleagues, for instance, provided participants in a study of presbyopic contact lens correction with a printed score sheet, but the letters on it were computer-generated [122]). This broader perspective on photographic media preserves a minimal association of photographic identity with photographic recording. The challenge has been central to arguments for recognizing both the artistic uses and capabilities of photographic images and techniques and the epistemic uses and capabilities of drawings and a variety of imaging techniques [83].

In the scientific context, the emblematic association of photographic images and processes with the epistemic ideal of mechanical objectivity [4] may be explicated in ways that recognize the epistemic merits and risks of both photographs and hand-drawn images. Already in the 1850s Elizabeth Rigby, Lady Eastlake, had extolled the distinctive capacity and business of self-less, unreasoning photographic machines to give evidence of facts through the superior sharp perfection, precision and detail of their images [123]. Eastlake was concerned with the relation of art to photography, rooted in science, and the scientific spirit, which she likened to accounting and its morality of exact balances, resisted the association of beauty with “a slight blur” (pp. 460–61, 1). It is around that time that photography was applied, for instance, to recording meteorological phenomena still within the conventions of fine art; and the astronomer and engineer James Nasmyth was pitting scientific photography against painting to reject artists’ geometric convention of representing lightning with a zigzag, distinguishing “artist’s lightning” from “true lightning” [124]. Sharpness—precision and exactness—is truth and supported by a reliable enough natural process, also objectivity. It was not long before scientists were partnering with photographers at the service of their scientific goals [2]. Still, one cannot ignore in so-called artistic images a cognitive, representational function for blur in the persistent use, for instance, of shadows, fog, or color ([1]: Chap. 1). Elsewhere I have also discussed the blurred aesthetics in contemporary artworks such as Gerhard Richter’s paintings in relation to science and, in his case, his own reference to the East German culture of materialist realism and his interest in the notion of indeterminacy in quantum physics (Chap. 11).

If photographs and drawings have merited, and still do, any credibility, this can be traced to the fact that both share belief-independent feature-tracking processes that operate in selective ways and under controlled conditions and social norms [83]. The information about their object of depiction, tracking visible features, was only warranted in photography by the limits of recording functionality of the photographic medium and processes (Meskin and Cohen find the distinctive value of photography, over ordinary vision, even assisted, is the convenient decoupling of visual information, feature-tracking, from information about the object’s subject-relative spatial location; but the merit might be unfounded [125]). What processes, what norms, and how and how systematic selection and control are effected may differ, also in degree, in the way, for instance, hand-drawn images may be attributed lower credibility on account of the higher unreliability of the complex neuromotor process of eye-hand coordination (i.e., a less robust and reliable signaling mechanism). Strict, but not necessarily automated, protocols and procedures of interpretation and depiction establish the scientific value of drawings, e.g., in archeology [126], or the value of painted photographs, e.g., in astronomy [83], which, like so many photographs paired with diagrams, derive much of their scientific value from the belief-dependent, theory-based, intentional, and conventional auxiliary graphic elements—similarly in non-photographic, functional MRI images, and computer simulations [127].

In the broader scientific context, photography enhances the exercise of eye vision and expands its scope. It adds, in this function, to the transformative–not merely documentary, reproductive, or recording–way of presenting and representing that ordinary and artistic photographs can contribute. Their enhanced realism and the tracking resolution and reliability have long made them valuable sources of information and evidence, that is, reality and credibility. The following are the distinctive relations photographs of blurred vision bear to their target subject matter: (1) a model-based, inductive inference coupling the intended object of representation (a subjective visual phenomenon) and the hypothesis regarding the process of its production, the optical explanation; (2) the decoupling of the intended object of representation (a general type of subjective visual phenomenon) from the causally connected, tracked, or indexed, particular object, a particular light distribution at the particular location and time of the photographic event; and (3) the fact that drawings track the particular subjective event and may also depict the general type they instantiate, while the photographic process and product simulates its objective optical features and causes. In the cases I am examining, the issue of credibility or evidentiary value is different from but often related to the representational value of the images. In particular, whether by singular causal connection of general physical analogy, there is a difference between representing or illustrating an image and also representing the optical processes that explains it. Different kinds of representations and processes of production might differ.

Drawings, then, may act as photographs by tracking (causally) the features a particular subjective phenomenon, the mental representation of a retinal image, while photographs act as drawings by imitating or illustrating (objectively) a type and a theory (a general classificatory and explanatory truth). Still, regardless of their representational value or accuracy, both kinds of images (insofar as they may be differentiated materially, socially, or historically) may be used as tools qua visual targets for the purpose of comparative testing. Both kinds and both uses play key roles in clinical practices aimed at corrective treatment. As I discuss in Sect. 42.5, a new kind of photographic technique brings this photographic image closer to the drawing's access to the target subjective image. The new process, however, unlike the act of drawing, involves digital computational processing (of course one could argue that also drawing relies on some form of computational processes, only in the body, or at least the brain).

Now, testing and evidence apply to different kinds of things. Besides demonstrations of optical conditions and their explanations, photographs of blurred vision have been used also to demonstrate clinical techniques of diagnosis and correction. Photographic evidence with blurred images has been used in support of the reliability of two related but different kinds of techniques: tests and treatments.

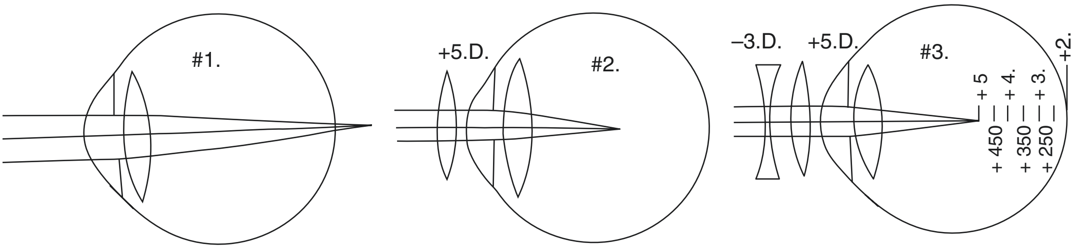
An early example of a diagnostic test subject to photographic demonstration with blurred images is J.E. Littlefield's fogged chart in his clinical manual, *Optometry: The Littlefield system of Eye and Nerve Measurements* [21]. The Kansas City eye doctor and educator popularized the fogging system for eliminating accommodation in patients' eyes. Littlefield's campaign against accommodation aimed at both reliable diagnosis and effective treatment; they are inseparable. In fact, for Littlefield the treatment consisted not only in the correction of refractive error but also in the necessary control and even prevention of accommodation. He considered the mechanism of accommodation an obstacle to the exact measurement of error magnitude and, more importantly, a root problem: (1) as a mechanism of compensation for the refractive error of the crystalline lens, it was a cause of loss of so-called vital nerve force, or nerve energy, and of the ulterior symptoms widely believed to be effects of such losses—fatigue, headaches, stomach trouble, and other nervous diseases—(p. 65) and (2), in its pathological spastic state, it was a cause of visual impairment in its own right. For Littlefield, then, preventing (1) would also prevent (2).

He defended the fogging system as a "more rational and scientific way" of controlling accommodation than the common use of atropine eyedrops, which had disruptive effects on patients' ordinary life and work (p. 75). The method consists in inducing a degree of artificial myopia, which he estimated at 2.5D, sufficient to blur the normal perception of every test-type on a Snellen chart ([27]: pp. 704–5). Then, with the information about the degree of induced myopia in a patient and about the size of smallest types the patient could read, one can estimate the magnitude of "natural" error and of the corresponding required correction (Fig. 42.42).

The patient with, for instance, hypermetropia might be able to read some of the types on the chart depending of the degree of error. At this point in the presentation, Littlefield considered it helpful to the student to reproduce a photograph that illustrated the patient's effectively blurred perception of the chart: "To aid you in understanding what degree if fog I mean when I say 'fogged out' I have had the photographer give me a blurred plate" ([21]: p. 99). The photograph showed how the blur induced with 2.50 lenses might still allow the patient with 0.75D of hypermetropia to read the top two lines of test-types on the chart (Fig. 42.43).

Littlefield's photographic imitation did not aim to demonstrate an optical explanation, that is, its significance as the evidentiary record of the result of the explanatory optical process. It aimed to demonstrate its place, and its meaning, in the application of a corrective technique.

In a similar spirit, but with a more explicit evidentiary aim, the also American eye doctor William Crisp, in Denver, Colorado, used photographs of blurred astigmatic vision to defend the diagnostic value of the cross-cylinder technique for subjective refraction [128]. This technique involved a compound cylindrical lens with a circular shape and opposite powers along perpendicular diameters (a combination of a convex cylinder and a concave cylinder of the same power with axes perpendicular to each other; a development of Stokes' cylindrical lens from 1849, discussed by Donders, a set of plano convex and plano concave lenses that could be rotated over each other, in a more flexible arrangement than so-called Jackson's cross cylinders). The instrument and the technique had been introduced by Edward Jackson, Crisp's neighbor, and colleague, first in 1887 and subsequently in



HYPERMETROPIA
FAR SIGHTED

FOGGED WITH +5.D.
NEAR SIGHTED

CORRECTED WITH –3.D.
MADE NORMAL BY +2.D.

Fig. 42.42 Diagram of an example of application of the fogging method on a patient's hypermetropic eye (from J.E. Littlefield (1905) *Optometry*, 74)

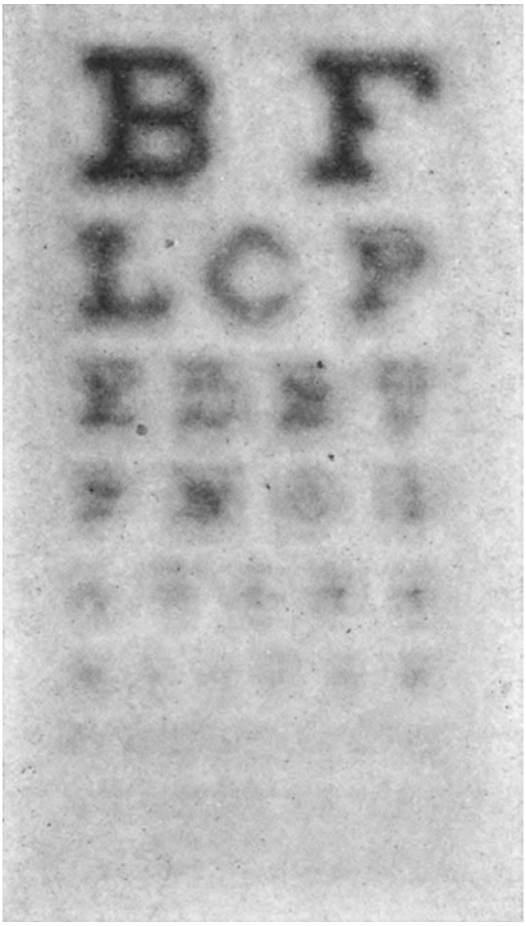


Fig. 42.43 Photographic imitation of fogged perception of a Snellen chart (from Littlefield (1905), 99)

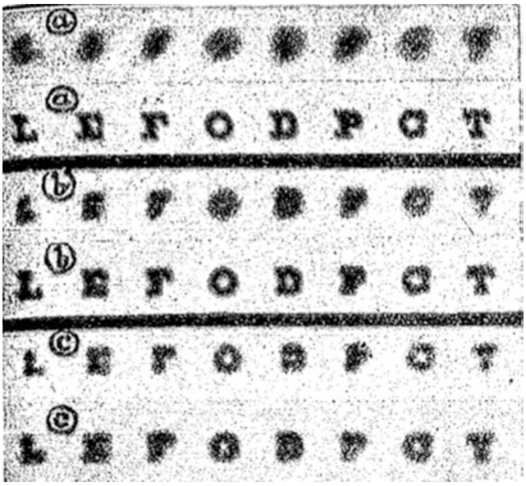


Fig. 42.44 Photographic imitation of an astigmatic patient's visual experience during a cross-cylinder test comparing different cylinder powers (from W.H. Crisp (1923) "A Plea for the More General Use of the Cross Cylinder," in *American Journal of Ophthalmology* 6, 211, Fig. 3)

1907. He had suggested their use as a tool for determining the principal meridians (axis) and the degree of astigmatism (power). The correct prescription is determined when the test-types read along the perpendicular meridians match, neutralized or balanced, with equal blur.

Crisp complained that the technique couldn't be learned without optical demonstration and lamented that the three previous papers introducing it included one sole illustration (p. 209). In addition to five photographs illustrating different arrangements of the lens, Crips introduced two photographic illustrations of his own making in which "the photographic camera has been made to imitate as closely as possible the appearances produced to the patient's eye during tests with the cross cylinder for strength of cylinder correction" (p. 211, Fig. 3 caption) (Fig. 42.44).

Like Littlefield, Crisp appears to have considered access to the patients' visual experience relevant to understanding and carrying out the examination test. The camera provided the stand-in model for reproducing and recording the visual effects of the series of optical conditions making up the test. And so he declared in a follow-up paper, in which the earlier photographs, additional ones and a detailed description of the photographic process involved in producing them entered his discussion of the test: "It was in 1921 that I first developed the idea that understanding of the cross cylinder might be appreciably facilitated by a series of photographic demonstrations, in some of which the photographic camera was, as it were, itself made to undergo the test for astigmatism by means of the cross cylinder" ([129]: p. 730). In his discussion of the photographic process, Crisp adopted an experimental standpoint to emphasize that the demonstrative value of the photographic series relied on the relevant variations in the pictures of different steps of the test; and isolating such differences required an adequate control to guarantee a sufficient "uniformity of technique" and "identical conditions" (p. 731).

I have noted that already in the earliest photographic demonstrations of optical hypotheses, the photographic method allowed for critical responses that appealed to the authority of the same graphic standard. The debates took for granted the value of the pictorial medium. The same can be said about the application of a photographic method to diagnostic techniques. Tests became increasingly scrutinized for their comparative reliability. And in this sense, Crisp's photographic argument was for several decades the target of a number of challenges presented in photographic images.

In 1940 the New York eye doctor Joseph I. Pascal published a study of different tests for astigmatism (for axis location and error magnitude) with the clinical aim to identify relevant differences. He was not seeking a general explanation or procedure that would fit all cases; instead, he was open to the practical value of the availability of multiple tools. In his view, as he put it, knowledge "of the conditions under which each test is most reliable will enable one to utilize them all more effectively" ([130]: p. 730). in some cases he recommended using several methods. The empirical basis for such a methodological attitude was a clinical difference between the optical behavior of lenses and the refractive errors in human eyes. The widespread mistake, he warned, was "to look on refractive errors too much as definite static entities similar to the trial lenses" (p. 729). Instead, the "dynamic physiologic and psychologic limits of the visual function" in both patients and examiners, the encompassing subjective circle, should lead us to assume that the same examiner would make different determinations of the error in the patient's eye at different times as would also different examiners at one time. Having said that, he reported that a larger number of patients responded to cross-cylinder test better than to line charts (p. 730).

The central issue, pointing back to Littlefield's proposal, concerned the relative benefits and challenges of fogging. Aside from practical benefits in terms of facilitating patient response, Pascal adopted the nineteenth-century point-source approach to astigmatism and used the features of diffusion spots as a measurable predictor of patient's visual acuity. The operative criterion was the following: vision with smaller diffusion spots was better than with larger spots, and vision with circular spots was better than with oval ones (p. 726). The diopters along different meridians would result in diffusion spots acquiring different shapes and sizes. In a number of indeterminate situations combining different shapes and sizes, the patient would easily make a subjective judgment leading to a mistaken assessment and, for instance, a prescription for overcorrection. For cross cylinders, Pascal concluded that the determination of the principal meridians required minimal fogging and that for determining the magnitude of error in each, fogging was a liability, the test being most unreliable with the eye was fully fogged. By constrast, the test was most reliable when the retina was placed in the midway position between different focal lines (p. 729).

From London, the eye doctor F.A. Williamson-Noble turned Pascal's conclusions into a photographic argument against Crisp's recommendation of cross cylinders [131]. Crisp acknowledged the methodological value of relaxed accommodation and, in the case of astigmatism, made a slight suggestion of the value of minimal fogging ([129]: p. 495). For Williamson-Noble, the photographic demonstration of the reliability of the cross-cylinder test relied on the contrast between the use of fogging and its avoidance, in both emmetropic and astigmatic patients. The graphic interest is twofold: the fact that Williamson-Noble felt compelled to present a photographic argument and that, in particular, he portrayed different steps (for angle of axis and strength of correction) of the test by combining photographic simulation and Pascal's calculation of the diffusion spot—the distorted blur circle—which facilitated the application of Pascal's independent evaluation criterion (Fig. 42.45).

The challenge prompted a response by Crisp. It consisted in a journal editorial on the method of photographic demonstration in general and, responding to Williamson-Noble, on Crisp's own

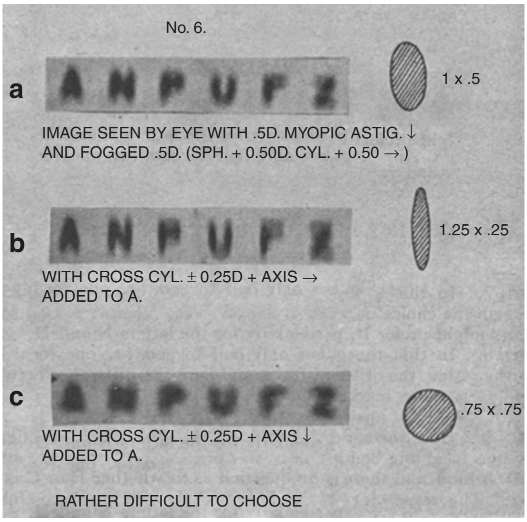


Fig. 42.45 Photographic reproduction of an astigmatic patient's visual experience of a cross-cylinder test with fogging (from F.A. Williamson-Noble (1943), "A Possible Fallacy in the Use of the Cross Cylinder," *British Journal of Ophthalmology* 27, 7, Fig. 6)

application to the test in question [132]. Despite its brevity, Crisp's discussion seems unique in the pictorial tradition I am tracking. It differs from Bull's remarks in its sustained methodological focus, and in an analysis that is explicit, comprehensive, systematic, and critical.

In the discussion, Crisp drew attention both to assumptions and constraints, starting with the general analogy between the eye and the camera. And, like Bull, he was quick to note distinctive features of eye vision such as dynamical focus scanning a scene the camera can bring entirely into focus all at once and the actual experience and interpretation contributed by the brain connected to the eye. He also opposed the occasional artistic "blurred mimicry" of "soft-focus' painterly effects to the predominant application of photography, namely, to "the production of sharply defined representation, so as to give the most accurate information possible concerning the thing or scene photographed" (p. 759).

Within the scope of educational application, Crisp distinguished between the dominant application of the sharp standard and the more limited application to teaching refraction techniques, which involves "representing the blurred appearance of the test letters as seen by a myopic or astigmatic eye" (ibid.). For the particular case of the cross-cylinder test, Crisp reproduced his earlier point that the series of photographs required to imitate the effects of each step in the test could only show the relevant differences if the results were "scientifically comparable," and the comparison required uniformity of technique and conditions (ibid.). He finally responded to Williamson-Noble's criticism and rejected having claimed that the best results involved fogging, only that "the patient's eye was not appreciably fogged not the accommodation appreciably active" (p. 760). Accommodation, in fact, introduced yet another difference between the eye and the camera: that it allowed the eye to provide accurate information by compensating for a certain artificial measure of defocus.

The photographic study of the cross-cylinder test was revisited in the 1980s [134, 135]. The authors sought to test the empirical assumptions supporting the cross-cylinder test, explicitly endorsing Pascal's assessment questioning the absolute and universal reliability of cylinder rotation techniques. The basic assumptions guiding the diagnostic technique are two: (1) the endpoints of axis and power determination are equally blurred and (2) the two compared images approach each other linearly—that is, there exists a linear relation between axis angle and power diopters ([134]: pp. 355–56). Their quantitative data and predictions challenge the assumption of linearity with the so-called dipper effect, which undermines the reliability of the tests results and the correction treatment (p. 358). Of more interest from a methodological standpoint, Sims and Durham presented their study as a mathematical and optical methodological hybrid producing quantitative and visual, optical, data and providing, respectively, mathematical and optical evidence (p. 356). They referred to the optical part as a "photographic study" and a "photographic experiment" and to the optical findings as "photographic evidence" (Ibid.).

As part of their photographic experiment, they sought to reproduce their term; they also use "repeat," photographic experiments by Crisp and Williamson-Noble and to replicate—also their term—the respective photographic findings, namely, that the equally blurred endpoints on the Snellen chart at an axis of 60° (Crisp) and 180° (Williamson-Noble) (p. 355). The reproduction did not involve any original photographic techniques and conditions, only the standards of cross-cylinder testing and photographic methodology, the latter simply based on the application of consistent and controlled photographic technique. In their case, the technique involved photographing the images displayed on a video camera recording the test procedure (p. 360) (Fig. 42.46).

They concluded that, regarding the first assumption, the images in were not equally blurred at the same angles and, regarding the second, that "photographic evidence confirms the mathematical predictions" (p. 374). Crisps findings they could replicate for 67° and not 60°, speculating that Crisp misaligned his cylinder by 7° (p. 378). Williamson-Noble's findings could not be replicated, suggesting his photographer's manipulations as the most likely explanation for the photographed results (ibid.).

The article's discussion raises the broader issue of the relation between the eye and the camera, referring to earlier discussions by Bull [100], Crisp [132], and Puntenney [135]. Sims and Durham added a difference traced to the action of cross cylinders and to differences between the three-dimensional features of recording film and the retina, namely, that the video and photographic camera lenses are more sensitive to blur from astigmatic distortion, while eyes are more sensitive to anamorphic shape distortion ([134]: p. 379). In a subsequent, expanded version, Sims developed the study of anamorphic effects ignored by Crisp ([133]: pp. 702–3), with photographic reproductions of the effects that Crisp should have demonstrated for the cross cylinders at 60°.

Material photographic records, even from digital sources, provide public access, temporal stability, and the spatial proximity that facilitate the conditions necessary for comparison and public dissemination of the visual argument. Crisps' and Sims' juxtapositions are examples. But it still a matter of intersubjectivity. Most evidentiary value involves comparative visual judgment on the viewer's part; and the visual information is always relative to the vision status of each viewer and their optical-muscular-neurological system—what I call the subjectivity circle.

The studies by Crisp, Williamson-Noble, and Sims and Durham show the practical purpose of using photographic simulations. What the sequence of studies demonstrates is a turn to photographic authority in order to publicly establish or challenge the reliability of tests as well as explanatory hypotheses. The alignment of interests in practical value and objectivity sustained a community interest in the production of the images under different conditions and technologies; and, with the evolving available technology, in the 1980s they provided the incentive for the introduction of computer simulations.

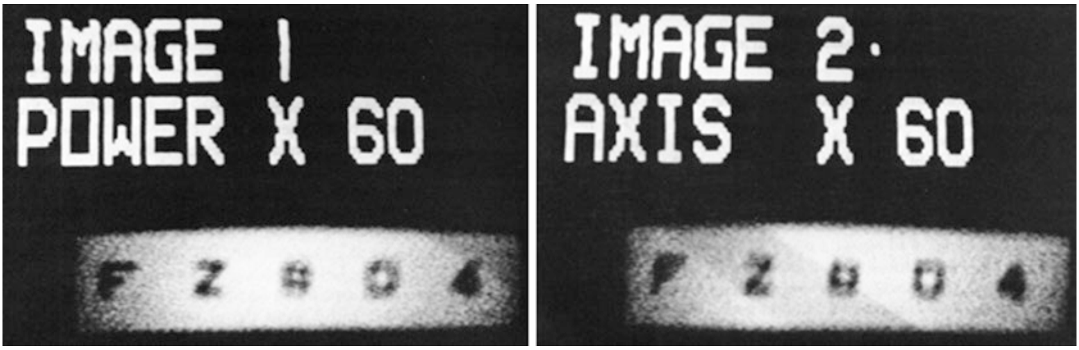


Fig. 42.46 Photographic reproduction of patient's experience during a cross-cylinder test (from C.N. Sims and D.G. Durham (1986), "The Jackson Cross Cylinder Disproved," *Transactions of the American Ophthalmological Society* 84, 375–76, Figs. 18 and 19, resp. Published with permission of the American Ophthalmological Society)

One early technological development was cinematography, and one practical purpose for its application, besides entertainment, was education. With such a value attached to films since the 1910s, it is not surprising that one can find at least one film documentary with photographic demonstrations of eye vision and eye tests. One example is the American short educational film *Through Life's Windows* (1919), by Paul Hugon and Floyd Ramsdell. Besides showings primarily in elementary and secondary classrooms, it was shown at the 1929 American Optometric Association Annual Congress [136]. The film was commissioned by the American Optical Company to a new studio, the Worcester Film Corporation, of Boston, partly building on the Edison Studio educational department. It featured simulations of visual conditions such as hyperopia and a dial test for astigmatism (Fig. 42.47).

The purpose of the visual demonstration is obviously to illustrate the conditions and the test is illustrative. In fact, the film asserts the analogy between the camera and the eye. It is also worth noting that, rather than showing merely a sequence of slides with still images depicting different cases or situations, the dynamic, temporally extended character of the film's images is used quite effectively. Both in science and education, this intrinsic characteristic of films allowed for a new dimension in the enhancing or transformative role of pictures, making visible characteristically temporally extended features and phenomena such as processes, or beliefs about them [137]. For instance, the film uses a diagrammatic animation that shows the progressive refracting effect of different kinds of lenses intercepting the path of light rays expressing their active, causal role in a physical process, away from purely geometrical models; in the test, the reproduction depicts the progressive, gradual nature of the administration of the dial test and the nature of astigmatism; in the same spirit, the diagrammatic images of the test and photographic images featuring a moving sailboat show the effects of correction in a gradual way.

Yet another kind of photographic picture of tests—tools, procedures, or results—presents an unavoidable element of blur one might call constitutive. To the extent that the visual content of photographs is available only within what I have called the subjective or subjectivity circle, always dependent on the vision status-refractive or otherwise—of the viewer, even relative to a corrected or normal level of performance —some test charts include types within a range of sizes or

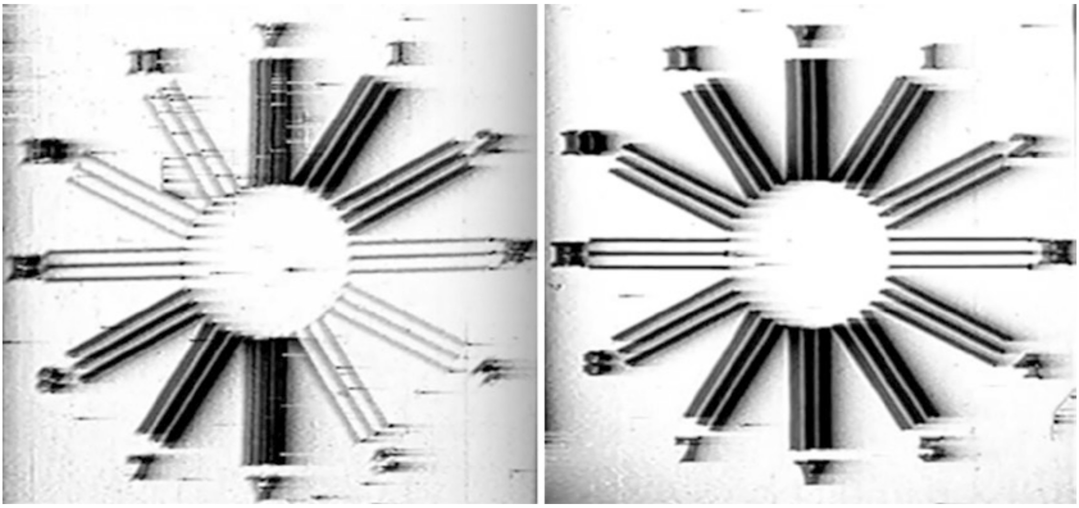


Fig. 42.47 Stills from a film simulation of the perception of a dial test chart with astigmatism (left) and in the process of correction (right) (from the documentary Through Life's Windows (1919), by Paul Hugon and Floyd Ramsdell. Images courtesy of The Archives & Museum of Optometry, Optometry Cares—The AOA Foundation)

other spatial features such that some might fall below a certain threshold and will be perceived as blurred. A case in point is the contrast sensitivity chart. One typical kind features a spectrum of gradually fading letters (a Pelli-Robson letter chart); another, a grating with increasing spatial frequency (a Campbell-Robson grating chart). The relative difference between the luminance of visual target and background can easily fall below a contrast threshold for a high or low enough frequency [45] (Fig. 42.48).

I indicated above that the demonstrative application of the method of photographic simulations extends from illustration and testing explanatory models to clinical interventions. While clinical interventions as well as research include diagnostic classifications and examinations, or tests, in clinical interventions, these are ultimately related to the possibility of corrective treatments. Next in the exploration of the photographic method, I turn from examples of photographing tests to examples of photographing treatments. Both aim at demonstrating, or testing, the reliability of their relevant techniques and instruments. Of course, these distinctions are relative: diagnostic tools and techniques have been used in the illustration and the testing of explanations; also, the assessment of diagnostic tests and the assessment of corrections may be related to the extent that the result of corrective treatments may be of further diagnostic value.

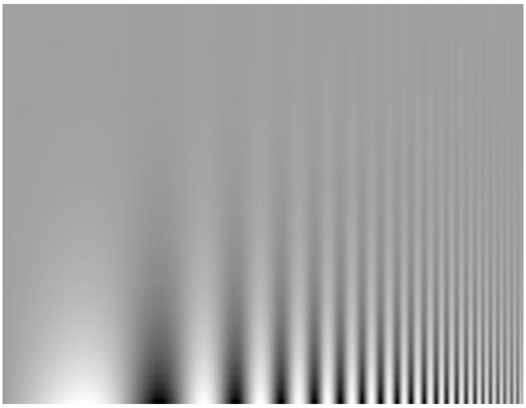


Fig. 42.48 Campbell-Robson contrast sensitivity chart (Courtesy of Izumi Ohzawa)

David Guyton joined the controversies surrounding astigmatism from the standpoint of assessing and improving understanding and correction with the use, in his own terms, of photographic simulations [138]. His target was the role of corrective cylindrical lenses in causing distortion in retinal images. Monocular distortion is caused by meridian magnification and is amplified in bifocal vision, often leading to intolerable errors in stereoscopic spatial location (p. 178).

One misconception with clinical consequences, he claimed, is that slanted images are intrinsic to the optics and experience of uncorrected oblique astigmatism—original or residual—and that the distortion is reduced or eliminated by the standard corrective lenses (p. 181). Guyton traced the misconception to self-experiments involving artificial simulations of astigmatism that lead to the experience of distortion. The explanatory analogy behind the artificial conditions in experiments might be liable to gross error. The epistemological risk here is not circularity in testing optical explanations but the methodological transfer of misunderstanding of the lens to misunderstanding of the eye. Indeed, the fallacy, he notes, is "that the trial lens simulates the effect of a *spectacle* lens and not the effect of an astigmatic cornea" (p. 182, original italics). Instead, geometrical analysis shows how the distortion increases not only with the power of the cylinder but with distance from the entrance pupil (p. 181).

By way of empirical demonstration, Guyton reproduced a comparative series of juxtaposed photographic simulations of distortion with oblique astigmatism (Fig. 42.49). The one on the left presents no astigmatic experience and no distortion; the center one simulates uncorrected oblique astigmatism with the retina between the two focal lines in Sturm's conoid, that is, the circle of least confusion or maximum acuity, and no distortion; the one on the right simulates the lens-corrected oblique astigmatism, presenting significant distortion. The photographs have demonstrative value: illustrative and evidentiary: each illustrates, in a taxonomic way, a condition, and the comparison implies that distortion is

Fig. 42.49 Photographic simulations of distortion with oblique astigmatism: no astigmatism, uncorrected astigmatism with the circle of least confusion on the retina and lens-corrected oblique astigmatism (from D.I. Guyton (1977), "Prescribing Cylinders: The Problem of Distortion," in *Survey of Ophthalmology* 22, n. 3, 183, Fig. 6. With publisher's permission)

Fig. 42.50 Photographic simulations of different alteration to corrective cylinders for oblique astigmatism: unaltered correction, reduced power, and rotated axis (from Guyton (1977), 185, Fig. 7. With publisher's permission)

uniquely associated with cylinder correction, as predicted by the geometric model.

Finally, Guyton addressed the challenge of reducing the distortion caused by the corrective cylinders. Besides shortening the distance between lenses and pupil, he suggested rotating the cylinder axis—to correct the direction of distortion—and reducing the cylinder power (pp. 183–84). The alterations lead to blur from the amount—not axis—of the residual, uncorrected astigmatism. There is a trade-off between distortion and blur. By way of demonstration, Guyton produced another comparative series of photographic simulations corresponding to three alterations: full correction with distortion, reduction of power with reduced distortion, and reduction of power and axis rotation (to 180°) with improved direction of distortion (Fig. 42.50). Blur occurs when the alteration leads to a decreased distortion.

Guyton did not cite or challenge any previous photographic argument as such—although he cited Williamson-Noble's discussion of the role of vertical clarity in letter reading in the paper with the photographic non-controversy over fogging—but he was in fact extending and contributing to that particular line of debate and methodology of demonstration by photographic simulation.

In a subsequent article, Zisser and Guyton reported another photographic simulation—their term—aimed to test the image quality of three types of bifocal intraocular lenses [139]. The lenses provide focused images of objects, near and distant. Zisser and Guyton challenged what they consider a misconception, the claim that out-of-focus light for the image of an object at any distance can be completely ignored rather than tolerated and “demonstrate this loss of image quality photographically” (p. 324). They adopt as a measure of quality the relative blur of out-of-focus images associated with loss of contrast. The photographic images they reproduce show two black-on-white letter charts at different distances and with the focus on the near chart only (with the distant one illegibly blurred out of focus), on the distant chart only (and the near chart illegibly out of focus), and both charts on focus (they specify the use of Nikon F3 camera with a 55-mm, f 3.5 lens, Kodak T-MAX 100 fine-grain film, and a 5-mm entrance pupil). The pictures show up to 50% loss of contrast when both charts are on focus. The role of the simulation is evidentiary.

In Holladay et al. [140], the authors also tested the optical performance of multifocal intraocular lenses relative to a monofocal kind. As measures of performance, or image quality, they determined and compared the different values of resolution efficiency, contrast, modulation transfer function, Strehl ratio, through focus response, 5% cutoff and contrast sensitivity. Besides laboratory testing and evidence with an artificial eye, they perform what they call photographic testing with black and white negatives and color transparencies (they provide the technical specifications). The latter was based on the judgment of photographic images of a Snellen letter chart, a Kodak color chart, and a Pelli-Robson contrast sensitivity, taken in water simulating the aqueous humor in front of the crystalline lens under ideal conditions—no decentration or tilt, and a 3 mm pupil. Given the constraints from the need for uniform illumination, the distances involved were shorter than a patient would experience. As a result, the authors introduced compensation factors such as magnification in order to simulate the distances in clinical testing conditions (p. 416). The assumption, as usual, is that the judgments and comparisons take place within a relatively standardized subjective circle of viewing conditions, either natural or corrected.

The comparative assessment suggested a superior depth of field for unobservable blur differences among the multifocal lenses but also, as expected, lower contrast. The distinctive element of their photographic test was the use the color photographs from projections of the color transparencies; the only series they reproduced. The result is color mixing (blurring) between adjacent colors for multifocal lenses (p. 422) (Fig. 42.51).

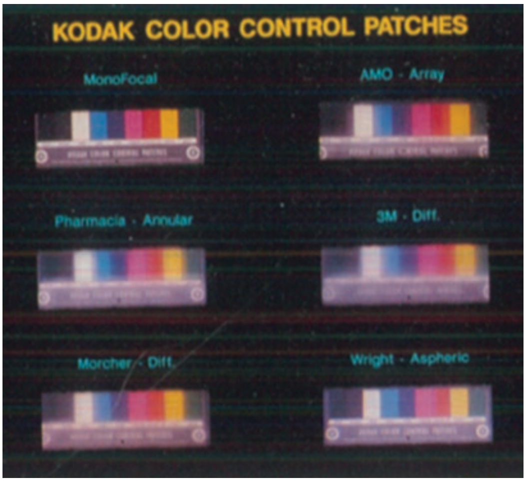


Fig. 42.51 Photographic simulation of color vision with monofocal and multifocal intraocular lenses (from J.T. Holladay et al. (1990), “Optical Performance of Multifocal Intraocular Lenses,” *Journal of Cataract and Refractive Surgery* 16, n. 4, 422, Fig. 5. Permission requested)

In the paper, Holladay and the other co-authors chose to publish only the color simulation. Since their earliest introduction, photographic pictures were and still are used during research and mentioned in published papers, they were and still are even publicly shown, for instance at conferences and classrooms, for research communication and education, but they were and are not all published. Some publications include none of the photographs that support their results.

The methodology of photographic simulations had developed further by the time the studies by Guyton, Holladay, and their co-authors were published. The techniques of optical, analogical photography were now supplemented with, and gradually replaced by, electronic, or digital, image processing. The development raises at least two issues that have become central to considerations of a connected development of computer simulations, and I will revisit them briefly in the next section. One issue is the identification of the photographic character of images and imaging processes and the extent to which digital photograph is photography. As I noted above, a broad approach to photographic processes prioritizes as distinctive identifying criterion the use of optical-chemical recording. From that standpoint, analogical and digital photography and their photographic images qualify indeed as photographic.

The other issue relates to the evidentiary value of photographic simulations. Especially, but not uniquely, in relation to explanatory hypotheses, I have pointed out that the two demonstrative roles, illustrative and evidentiary, differ. Illustration requires that the analogy pertains only to the final image product, the visible simulation of the subjective experience of a retinal image—anatomical-physiological-neural-cognitive processing. In the case of photographic experiments aimed to test or support one or more explanatory hypotheses, the aim includes the simulation of the process; the analogical argument, the analog simulation, extends to the physical model as well as the resulting image. As computational elements enter the production process, the analogical processing replaces the analogical process, and the analog simulation becomes at best partial. In cases of illustration of optical hypotheses, tests, and treatments, the processing counts at best as a partial analog, mainly with instrumental value, and is hardly presented as an explanatory hypothesis, even in support of a technique of examination or correction.

One example is the use of photographic images to illustrate the application of the so-called vision-multiplexing approach to corrective treatments, in particular to the design of low-vision spectacle lenses [141]. In conditions of unimpaired vision, we benefit from a wide field of view providing cues for navigation and orientation; an additional cognitive benefit results from high resolution for discriminating salient details, visual differences in our environment. Whether in connection to our dynamical interaction with the environment such as navigating and manipulating or to higher-cognitive purposes, in typical cases of single fixation or focus of attention, resolution varies with eccentricity or distance from the center of the field of view—in the retina located in the fovea. Spatial resolution and contrast sensitivity increase around the center of attention and drop off around it. Any detailed map of the environment is the product of a dynamical shifting of the centered resolution map as the eyes track different targets. The so-called tolerance for refractive error is then, in fact, a cognitively valuable use of blur. However, a number of ophthalmic pathologies are accompanied by a loss of high-resolution functionality.

Peli corrective proposal includes the design of peripheral prisms in order to achieve what he calls a multiplexing effect. The effect consists in integrating the wide field capability with high-resolution functionality associating with the field of view a relatively homogeneous resolution map (p. 569). The resulting experience integrates multiple fixations (Peli cites different modes of multiplexing, spatial, temporal, bi-ocular, and spectral). He reproduces a series of three photographs to illustrate the effect for an observer using the prisms (Fig. 42.52).

In the first and the second, the resolution distribution is centered around single points of fixation. In the third the higher level of resolution is distributed uniformly across the field of view integrating multiple fixations. Again, since an image's optical properties will be experienced differently by different viewers relative to the vision status, the perception of equal-resolution photograph is subject to its viewer's single-fixation effect.

Now, Peli indicates that the images have been generated with software. The software, provided by Wilson Geisler, was introduced to process, for instance, real-time video-communication signal [142]. It consisted in a video coder/decoder algorithm with a so-called foveated multiresolution pyramid. These kinds of iterative (pyramidal) algorithms were introduced in the early 1980s to take advantage of limitations of human perception to compress image data within those limits and to optimize electronic storage and transmission ([143]: p. 33, [142]: p. 294). In this case the relevant limitation is the resolution (sharpness) distribution around a maximum corresponding to

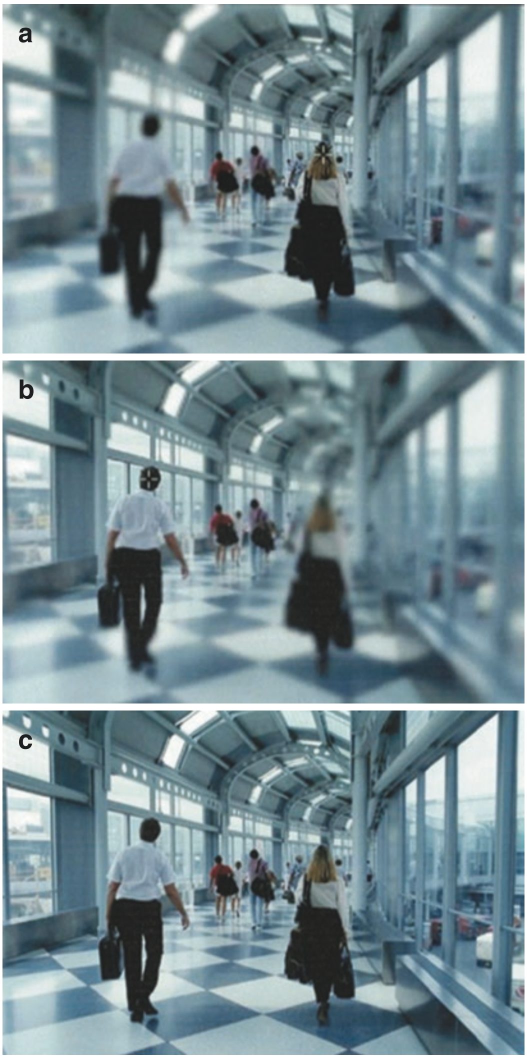


Fig. 42.52 Photographic illustration of the visual experience of single fixation with centered resolution map and of the multiplexing effect integrating multiple fixations across the field without blur (from E. Peli (2002), "Treating with Spectacle Lenses: A Novel Idea!?," *Optometry and Vision Science* 79, n. 9, 570, Fig. 1. With the publisher's permission)

a point of fixation. The algorithm performs a number of iterations involving subsampling from the array of pixels with the image intensity data and blurring with mathematical smoothing filters. The mathematical models of blur are the kernels of point spread functions that convolve with the mathematical representation of the original image (see Sect. 42.3). A Gaussian kernel, or Gaussian blur, uses a low-pass filter for averaging away high frequencies. A Laplacian operator is a reversible functional used by Geisler and Peli that uses interpolation to calculate differences. Mathematical models of blur and algorithms processing it are many; elsewhere I have discussed the application of rough-set and fuzzy-set theory and their use in neural networks [1]. Image processing, however, is not my focus here.

Adelson and his colleagues reproduced an example of a digital image processed using Gaussian (top) and Laplacian pyramids (bottom) (Fig. 42.53).

With the processing pyramid Geisler and Perry introduced virtual foveal fixation effect that removed resolution data around a designated area of fixation. Peli reversed the coding transformation to integrate multiple fixation points across the simulated field of view. The algorithm was based on human psychophysical data on resolution maps ([142]: p. 295), but neither Geisler nor Peli presented it as a model of an optical or neural process that explained and justified their application; only the resulting image is meant to be an analogical illustration of the observer's experience. Peli illustrated the results reported by patients.

Before drawing a few more general lessons, I want to draw attention to another work, by Cameron Parsa, Forrest Ellis, and David Guyton, that is doubly significant: It builds on prior applications of photographic simulation and discussions of its methodology and articulates a critique that integrates them both [144].

The authors acknowledge a long photographic tradition and its intrinsic simulational, analogical character: "For over a century, ophthalmologists have tried to use cameras to simulate what the human eye sees" (p. 1489). The acknowledge, in particular, the public use of photographs: "Photographs showing blurred and distorted images have appeared periodically in the ophthalmic literature with the purpose of simulating the blur and distortion seen by the uncorrected or ametropic eye" (Ibid.).

They also put forward a critique establishing the conditions of validity of the method, with two components, one negative and the other, positive.

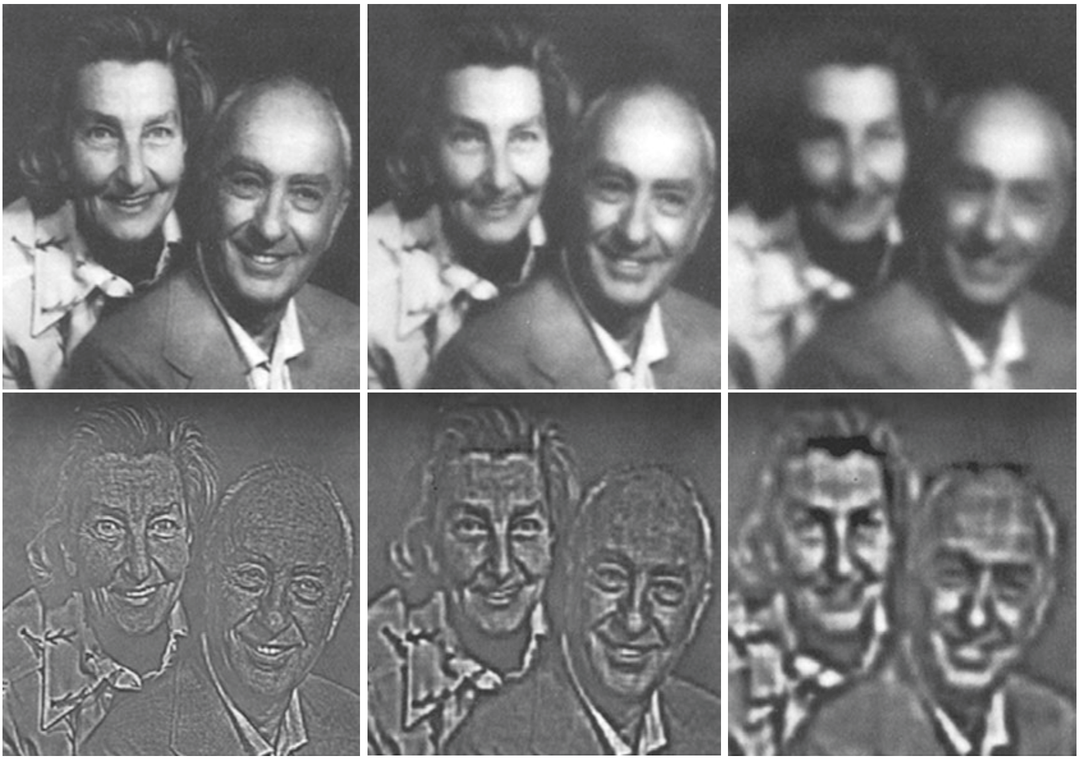


Fig. 42.53 Digital photographic image processed using Gaussian (top) and Laplacian (bottom) pyramids (from E.H. Adelson et al. (1984) "Pyramid Methods in Image Processing," *RCA Engineer* 29, n. 6, 35–36, Figs. 2b and 4b)

The negative targets the analogical assumption behind the method of adding an "error lens" to a focused camera, "the seemingly straightforward assumption that the camera will see what the eye sees" (Ibid.). Ignoring optical and physiological factors has led to authors drawing "misleading conclusions from their photographic demonstrations" (Ibid.). In the footsteps of some of the previous discussions, they reject making the assumption without qualification: "This assumption, however, is not true" (Ibid.).

Their original, positive—constructive and constitutive—methodological project is this: "to determine the appropriate settings for an ordinary camera which will simulate the relative blur of out-of-focus ocular images and the distortion produced by correction of astigmatic error" (p. 1490). Specifically, they aim to establish the "conditions which must be met in the optical system such that effects of diffraction do not override the geometrical analysis for out-of-focus imagery" (Ibid.). The demonstration is itself an application of the photographic method, but, to avoid circularity, it combines "graphical [geometric optics], mathematical [physical optics] and photographic support" (Ibid.).

The account distinguishes between real optical blur, or dioptric defocus, and relative blur, the basis for apparent blur relative to image size. Relative blur is defined as "the diameter of the blur circle from each object point relative to the object detail" (ibid.) or "the ratio of blur size to image height" (p. 1497). The physical analysis focuses on the limit on the sharpness of images that projected through an aperture set by diffraction—the Airy disk. Above this limit, for a size of defocus larger than a minimum proportional to the light wavelength, the geometrical analysis predicts the independence of relative blur from focal distance and the proportionality of relative blur to dioptric defocus and entrance pupil size.

The result is of methodological consequence, as it, the authors conclude, "allows us to infer that the out-of-focus and distorted imagery can easily and reliably be reproduced in various optical assemblies" (Ibid.). In turn, their photographs will count as evidence insofar as they are taken with strictly consisted conditions constrained by the physical limits of the validity of the geometrical model and its prediction. A series of four pairs of photographs are taken under such validity conditions, "well within the domain of geometric applicability of our equations" (Ibid.). Each pair is taken under the same value of the independent parameter, and the different values of other parameters show the dependence. Again, it is the comparative judgment that provides the evidentiary value; in this case for the empirical geometrical hypotheses, it "confirms the theoretical finding" (Ibid.).

Circularity is avoided because the evidence supports the geometrical, not the physical hypotheses. Residual error such as uncorrected astigmatism and conditions involving retinal architecture and neural processing may explain the difference in size between the simulated and the subjectively perceived blur. Only with this in mind, they conclude, accurate photographic simulation and verification is possible. Finally, for the authors the method carries two benefits: (1) Its evidentiary value supports illustrations, hypotheses and techniques, which can be then adopted with confidence; and (2) in the case of techniques, the assessment can be carried out objectively, prior to—though not instead of—subjective and costly human trials (p. 1498).

I want to finish this section with a few lessons. Of the publications reported on above addressing photographic simulations, in a considerable proportion has their authors explicitly placing their papers in an extended literature on the photographic method, identifying and extending a particular lineage, and not just more recent precedents or targets. Connectedly, many such works present an element of methodological self-reflexivity expressed in the form of methodological analysis. This lineage organizes, in those terms, a minority but enduring pictorial and argumentative practice, theoretical and practical: illustrative, explanatory, and corrective. In particular, it is worth remembering that most of it gets connected together and extended around the application of the photographic simulation to enduring challenges stemming from the distinctive complexity of astigmatism.

Another lesson is more historical. The exploration in this section, above, suggests two historical sequences, without strict periodization, in the non-exclusive appearance of new kinds of pictures and kinds of applications. About kinds of pictures: the introduction of drawings is followed by the introduction of photographs; the photographs are used first together with drawings, then alone; also, they are first only optical, analogical photographs, then also digital and processed. I have suggested that the sequence may be explained by the introduction of new resources and standards. About kinds of applications: The aims of simulation begin with taxonomy—illustration—and introduce next explanation, tests, and treatments. The sequence of aims cannot be explained simply or easily. It is possible the stability of classifications of conditions and consensus around explanatory hypotheses and external incentives—about clinical correction—motivate subsequent and dominant applications.

The variety of kinds and applications is not only non-exclusive, but it has been repurposed to accommodate subsequent ones. Next, I will consider how the new regime of pictorial arguments is still a mixed one, although enforced around the rise of computer simulations.

42.5 Computer Simulations and the Current Pictorial Regime: Drawings, Photographs, and Computer Visualizations—New Kinds and Roles for Old Uses

I have indicated how practicing eye doctors and researchers refer to the role of photographic images and processes in analogical terms, as imitation, similarity, and frequently as simulation. To track the specific pictorial and methodological significance of computer simulations, analogical talk of simulation is not sufficient.

I have also introduced a weak but, for the purpose at hand, adequate enough version of a technical distinction between analog and symbolic simulations [103]. Analog simulations involve relevant similarity of causal structure. In this case I have substituted the specific physical processes represented by optical models of light's propagation through photographic apertures and lenses (media with different refraction indices). Symbolic simulations require an adequate relation of the simulated target system or phenomenon to some kind of computational, step-wise, rule-based, and possibly inferential, symbolic processing, i.e., an algorithm. The programmed algorithm provides the computer model; the simulation model is the computer model in relation to a target system to be simulated. The physical implementation of the computer model constitutes the computer process. Then the symbolic computation or processing is typically taken to be based on the encoding of formal relations expressed symbolically—the software—into the causal processes involving material components and states of the computer, the hardware. In relation to a target model, this computer process constitutes a computer simulation ([127]: Chap. 2).

Different sciences or the study of different kinds of systems of interest in the same science have recourse to a variety of such computational models, including mathematical equations—difference equations and discretized differential equations—, individual-agent-based rules for aggregations of many such units, multiscale representations (with parameters that bring models at different scales together on the same grid especially for relevant features below the spatial and temporal scale of the base grid), and randomized algorithms (Monte Carlo simulations) [127, 145, 146].

The computation is then considered a simulation of an independent target system or phenomenon if some structural element, or some kind of information, is also intended and used as its model (by some accepted criterion), without being reduced to a component physical structure or process alone in the computer or computation (the reduction is common to material theories of cognitive processing as mental representation) (Trenholme discusses this failure involving a potential breakdown of the distinction between analog and symbolic simulations in ([103]: p. 126)). Formal elements of the computation are considered to be similar enough (by some adopted metric and purposes) to the formal elements of the system or phenomenon of interest, whether its structure or its dynamics [127, 146, 148]. From my standpoint and for my purpose, the operative notion of symbolic simulation is linked to scientists' design and operation of digital computations that encode information, including information considered empirically adequate of the simulated system. It stands as an alternative to the photographic method, while the resulting images visualizing computations are often also compared with photographic images.

In particular, the new line of simulation can only be established by the accepted relation between computation and digital photography with electronic image recording, processing, storing, and display. This relation, however, depends in turn on the photographic status of digital photography; on the relation I discussed above of the photographic method to the system photographed and the resulting image displayed. The dominant view among practitioners and theoreticians is that digital photography is "really" photography, that it merits the label and its implications, e.g., that the resulting images are photographs even if displayed on a digital screen. In many optical computer simulations, however, the recorded image does not bear to the displayed image expected optical and isomorphic relations. More importantly, while photographic simulations claimed relevant physical and geometrical analogies between both the resulting images and between the optical processes producing them—that is, the explanatory model, for vision computer simulations—the production process (the computation) of the resulting virtual image might include empirically adequate information about anatomical and optical conditions. But it is not typically claimed as an explanatory model, or at least the computation behind the valued result bears a different status as representation and explanation.

The controversy on this point extends to many kinds of computer simulations. The epistemic status and methodological functions of the computational process are possibly the most distinctive feature of computer images and the most distinctive subject of methodological debates. Before identifying specific aspects of the optometric computer simulations in relation to the use of drawings and photographs, now it might be helpful for guidance to consult briefly discussions of issues in the so-called epistemology of computer simulations (as I have done with photography).

For instance, authors are often quick to distinguish between computer simulations and methods of visualization, the images displayed on computer screens. Two purposes of visualizations of simulation data are enabling non-linguistic communication (visual rhetoric) and calibration of simulation models ([146]: Chap. 2, 149, [127]: Chap. 5). Daston and Galison distinguish them from drawings and photographs as useful presentations rather than representations ([4]: Chap. 7).

Calibration, or benchmarking, seeks to show that simulation information matches empirical information from real-world systems, for instance, experimental data. Visualization is also an effective way to communicate and also, like photography or video images, a source of access to additional information contained in visible systems and in data sets, for instance, complex patterns or relations. When available and accepted experimental data can be recognizably visualized, the visualization of simulation data (or predictions)—the simulation outcome—becomes important so that judgments of similarity (a matter of expertise more than of objective metrics and mechanical procedures) can establish a match and support the reliability of the simulation model ([146]: p. 22). Visualization, in this way, may help also apply the quantitative information in the simulation model to visible empirical systems and phenomena.

A stronger epistemic claim attributes to visualization a cognitive role in understanding the simulation and the simulated target system ([127]: Chap. 5). As in the case of drawings and photographs, also for simulations, the effective performance of epistemic and methodological roles, from representation to evidence, depends on a variety of conventions and contextual standards [83, 107]. Except the specifics differ from cases of linguistic representation. The intuitive anchoring in concrete perceptual information, for instance, plays a pragmatic role in facilitating our processing of symbolic information in computational results.

Visualizations may also help identify problems in the mathematical model—or, when interpreted, theoretical model—implemented in the simulation through the computer model. It may help identify relations within the theoretical variables or the simulated data that contribute not only to understanding, and correcting the simulation model, but also features and behavior of the target system. For such purposes, the visualizations will typically require selective curating, editing, or idealizing, as does the design of simulation model itself ([127]: Chap. 5). They may include also additional levels of interaction as in the case of virtual reality—with the perception and exploration of the visualization through phenomenal immersion—and augmented reality with integration of the visualization in the perception of the target system. In the end, the different modes of visualization are taken to enhance effectiveness and efficiency, in a way uniquely dependent on visual experience, accessing salient information and pursuing epistemic goals such as measurement, prediction, and, more controversially, even understanding.

In principle, the claims seem quite plausible; humans are, after all, visually and spatially oriented cognitive agents. The controversy over understanding concerns the choice of operative criteria of understanding and their distinction, especially for visualizations, from a sense or illusion of understanding [148]. Understanding in the sciences may come in different forms, for instance: inferential—derivational and often counterfactual—integratory or unificatory, causal, interventionist, and pragmatic. In every case, the relevant cognitive activities and states are often tracked by psychological cues—the sense of understanding—which have been experimentally proven unreliable, giving only the illusion of understanding. Also, the illusion and its roots may have different forms, from a mentalistic perspective and a fallacy of composition based on access to elements of programming regulating the behavior of parts in the computational process, e.g., cellular automata, to a fallacy of maker's knowledge—privileged epistemic access to one's design and implementation of a computer model. In the case of visualizations, the risk stems from unfounded consequences of mistaking the simulation results for the behavior or structure of the target system, from unarticulated experience or tacit experience and lack of reliable guidance, or from extraneous visual cues introducing biases or artifacts (ibid.).

In the case of simulations of retinal images and aberrated visual experience, visualization is, needless to say, uniquely salient to the relevance of the computer simulations to their intended or subsequent purposes—they are called visual simulations. And key to making relevant use of the simulations is the visual similarity to retinal images in the distribution of light intensity.

What are the purposes of computer simulations? Answers in the literature on the subject that aim at being either general or inclusive point to goals such as heuristic purposes, measurement, prediction, exploration and explanation, or understanding (some accounts introduce explanation as a kind of understanding, with understanding as either a component or a goal of explanation, yet compatible with different standards of explanation). In what case, how or whether such purposes are achieved, and, no less importantly, about what are precisely the subjects of discussion [127, 146, 149].

The controversy over the methodological value of simulations originates in their ambiguous status, between the formal ideal of solving equations in theoretical models and the empirical ideal of testing theoretical results with data from measurements and experiments. Simulations are frequently used when empirical data is, for whatever practical or ethical reason, hard to come by and, then, results could hardly be tested against such data. They are frequently used also when mathematical equations in the theoretical model have no analytical solution for all points in space and time in a region where the phenomenon of interest takes place. In addition, the results of the simulation are produced by an algorithm implemented in the computer process out of more than just the mathematical model, e.g., with programming tasks, auxiliary technological items, mathematical assumptions and techniques, idealizations, etc.

Still, while practitioners often claim that the algorithms can be verified formally and the simulations validated empirically (ibid.), the corresponding practices are inseparable and non-standard, relying on partial comparisons with limited experiments and conditions of convergence and stability of results from different simulations [147]. The resulting epistemological and methodological debates involve such questions as: When simulations reproduce the behavior or structure of a target system, are they explanations? When they yield new information, are they exploratory experiments? Do they provide experimental evidence? Are they experimental tests?

At the heart of the controversy lie two more questions: one concerns the actual direct target of experiments and simulations—not the intended, more general external systems and validity—; the other concerns the material similarity between simulations, or experiments, and their target system, and whether the epistemological equivalence between simulations and experiments requires such material similarity. I have pointed to a related issue in relation to the analogical methodology of photographic simulations. The material similarity of analog simulations I have identified in the photographic approach is not a feature of computer simulations. Some authors have assessed cases in support of the methodological equivalence between simulations and experiments; others have argued for the opposite view, and yet others have argued for a limited similarity by appealing to the fact that empirical methodology is hardly less complex and messy than simulations. In certain conditions, simulations can provide more salient and reliable information [127, 147]. The relevance of such simulations to their target shares with photographic simulations a reliance on trust in (different) background knowledge.

The same disparity of views applies to the case of full or partial explanatory value of simulations, an issue, as I have noted, already raised by the users of photographic simulations. The issue partly depends on the role of idealizations and partly on criterion of explanation endorsed in the technical claims and in the methodological assessment. When empirical and causal interpretations are introduced in order to simulate the role of certain isolated factors, the simulation provides explanatory value, but it is only partial. When the explanation answers how-possibly questions rather than why or how-actually ones, the simulation provides potential explanations ([149]: p. 41–2).

Unlike in the case of photographic simulations, some computer simulations involve a trade-off between accuracy of assumptions and accuracy of results, so that descriptive and predictive accuracy (or validity) constrains explanatory accuracy (when the model reproduces accurately both the target's behavior and the operations resulting in that behavior, some authors speak of structural validity (pp. 35–7)). In some comparative models, the trade-off occurs between explanatory accuracy and accuracy of assumptions required for the comparative nature of the explanation, or at least the process establishing it [150].

Predictive validity alone is not always supported by explanatory models or principles (whether theoretical principles, general regularities, or causal mechanisms), but it requires some empirically adequate model supporting it, often statistical. Without it, the predictive value is reduced to the success cases, which are not sufficient to generate trust in subsequent applications. With accurate initial conditions (and calibration), the same criterion extends to the use for the generation of data as derived measurement outcomes [151]. For evidentiary value, the generation algorithm must obviously include a representation of the model under evaluation. One methodological challenge for models targeting complex enough systems, especially statistical models, is the generation of reliable calibration data; this has been called the problem of ground truth (in particular in the discussion of the challenge establishing ground truth for the evaluation of fMRI data through fMRI simulation studies, [152]).

Next, to conclude this study, I turn briefly to visual computer simulations of blurred vision. I have already stressed the centrality of visualization. Now I will draw attention to three other different dimensions: the different uses, the role of the ideal of objectivity, and the new auxiliary roles for drawings and photographic simulations.

Computational models, again, are not just mathematical models, even if their application requires computation ([153]: p. 14). Some models even aim to represent the working and structure of neural architecture and the neural processing of optical signals. This includes formulations of the so-called blurring problem and mechanisms of neural adaptation [48, 154] (including neurophysical models of noise and contrast functions ([24]: Chap. 14)). The blurring problem has been presented as involving, for instance, a pattern of divergence of locations from input elements of spatial information across layers in a pyramid modeling processing flow ([153]: pp. 43–4). Based on some model of the neural circuitry, neural adaptation contributes to filling gaps between different expressions of blur, for instance, in depth of field and in the absence of expected systematic relations between acuity and degree of aberration, especially below 2.5 diopters. Other extended anatomical-optical models consider more prevalent compensation mechanisms such as lens accommodation and pupil size reduction. They can reduce the effects on image quality of different kinds of aberration, the most important of which is optical defocus. When some mathematical model is involved in the form of mathematical equations and the results are said to be simulated, the computational model is nevertheless identified by the characteristics of the mathematical computation run on a computing machine, for instance, by the algorithm implemented for the intended purposes.

As I reported in Sect. 42.3, over the second half of the twentieth-century wavefront analysis became the leading mathematical approach to physical vision optics and the representation of aberrations in retinal images. Its analytical and principled structure contributed to the sustained enforcement of standards of objectivity that since the late nineteenth century have guided both theoretical and clinical practice. Central to the application of the wave-aberration model is the determination of point-spread functions (PSFs) for the density distribution of retinal rays, or light intensity, and the application of a number of quantitative metrics for image quality. The identification of different kinds and degrees of aberration rely on polynomial approximations that play a dual role of classification and measurement, e.g., Zernike polynomials.

This has raised two challenges for the pursuit of objective methodology: computation and measurement. In response, many efforts have been directed since the 1980s toward providing objective optical-computational hybrid methods of measuring, indirectly, PSFs (through Fourier transforms) and wave aberration. The computations get their objective empirical input from a discretized map of wave phases (optical paths differences) obtained using, for instance, a Hartmann-Shack sensor. The light rays travel through the pupil twice (hence called a double-pass method) and the phase map yields an aerial (reflected) image, which, modeled statistically, yields an aerial PSF from which the retinal PSF may be determined. The aerial image of the point test may be recorded by a camera and processed digitally. In this context, the role of the camera is not to yield a photographic simulation but to provide data.

Among the earliest works with this approach, Artal and colleagues proposed a retrieval algorithm for using objective data to determine the retinal PSF and the wave aberration, that is, simulated for the individuals whose data had been obtained [66]. They touted their proposal as an objective method to be distinguished from earlier, subjective methods. In the same vein, Artal and colleagues, and Navarro and Losada, subsequently introduced a so-called asymmetric double-pass or one-and-a-half-pass method to collect phase data associated with non-rotationally-symmetric aberrations and to control for the dominant contribution of diffraction at small pupil sizes—around 1 mm—[20, 66]. In the absence of ideal geometric conditions, the retrieval computation method is reliable in the approximation of a test "point" source (effectively, a Gaussian spot) that is much smaller than the resulting retinal PSF: a situation presented in cases of fully dilated pupils—larger than 9 mm. Since many aberrations (and blur size and patterns), even the effects of intraocular light scatter, depend on pupil size, the PSF is calculated relative to the one associated with the diffraction-limited value for the smallest pupil size, thus controlling for a non-aberration effect (similarly, the retrieved modulation transfer function as a measure of contrast sensitivity is related to both optical and neural factors ([23]: Chap. 18)). The resulting retinal error map can then be visualized by the computer.

In computational mode, the new pictorial methodology soon stepped into the earlier role of photographic simulations. It also revisited an early problem and assumption, namely, the optical explanation of star-shaped blur, with radiating patterns also known as starbursts. They constitute an entoptic phenomenon—it includes distinctive features that are not present in the accepted model of the stimulus or object source—resulting from staring at a bright point source. As in the case of Bull and Verhoeff [100, 114], a century later another debate over explanation took place, also based on pictorial methods, between, for instance, Xu and colleagues [64, 155] and Navarro and Losada [20], only now with new objective records and simulations. Another difference consists in the convergence of targets and evidence sources in the same individuals—and, derivatively, the same population. In their own way, photographic data and computer simulations joined the uses of other computer simulations: visualization, prediction, practical guidance, testing, and explanation. In the context of optometry and ophthalmology, those goals are often inseparable in the sense that one may be used as a means to another. Their distinctive way still involved the use of blurred pictures and, as Navarro and Losada acknowledged, "an objective-subjective comparison," only theirs, in the new objective ways, was one that had "not been done so far" (p. 353).

Navarro and Losada used photographs and computer simulations to test and eventually support an explanation of subjective star images. The explanation, going back to Helmholtz and Bull, consists of two embedded hypotheses: (1) that subjective star images have a purely optical origin and (2) that the optical cause of star patterns is a geometrically similar pattern of fibrous structures—so-called suture lines—in the lens acting as diffracting structures. The argument aims to support the general validity of the explanation by supporting the explanation at the individual level.

Unlike Bull's evidence from photographic simulation, they use photography to provide objective individual data to be subsequently used as evidence for the individual explanation, that is, the optical explanation of each individual case. This is a key shift not just in the use of photographs but in their representational role. Like drawings, this kind is, despite the image-processing component, causally linked to the individual optical and perceptual phenomena; simulations had aimed to represent by causal analogy and shared optical features. What, then, is the role of drawings? Their use signals the focus on the subjective perception, the subjective image, and not just the retinal optical image, as the ultimate target of representation, explanation, and clinical intervention.

Their argument is based on optical and computational models and actual processes and images, and on visual similarities based on what they call objective-subjective comparisons of pictorial records. The line of reasoning can be reconstructed in 16 steps.

1. Subjective star patterns—the star images in subjective drawings, or drawings of subjective images—are similar to diffraction patterns formed by optical processes such as in telescopes and with photographic lenses (pp. 353 and 357). This is the sort of similarity used in evidence from photographic simulations. According to the researchers, the similarity suggests the optical origin—in other words, an optical explanation based on a model of diffraction (p. 353). This was the form of the basic argument for the eye-camera analogy and, in turn, for photographic simulations (see Sect. 42.4).
2. The authors make a (conditional) prediction about individual cases: "if star images have a purely optical origin, then the optical PSF [for an individual retinal image] should display features similar to those of the star patterns reported subjectively by the same individuals" (Ibid.).
3. According to their wave aberration model, the individual optical PSF can be established to the best approximation through the aerial PSF reflected back through a fully dilated pupil. (Eyes are controlled for geometrical alignment and pupil size: presumably also for accommodation.)
4. The individual aerial PSF can be computed from data of the aerial image produced and recorded in vivo by a pixelated CCD (charge-coupled device) camera (Fig. 42.54). The aerial image itself is the product of a computation based on several camera exposures and background processing of the reflection of a bright point source in the form of a narrow incident beam from a Gaussian spot.
5. Photographic records are taken for corrected eyes and for eyes with different aberrated conditions, introduced artificially with additional negative and positive dioptric power.
6. Individual observers use graduated systems to provide information about the size of the subjective star image and sketch the perceived pattern in pencil on paper. Individual observers depict and measure the perceived star images for different aberrated conditions, with additional negative and positive optical power (Fig. 42.55).
7. The objective photographic images (standing for the inferred retinal PSF, which in turn is expected be similar enough to the subjective, perceived image) are compared among themselves and with the subjective drawings for geometric pattern, size, orientation, and dependence of size on refractive state—the added positive and negative diop-

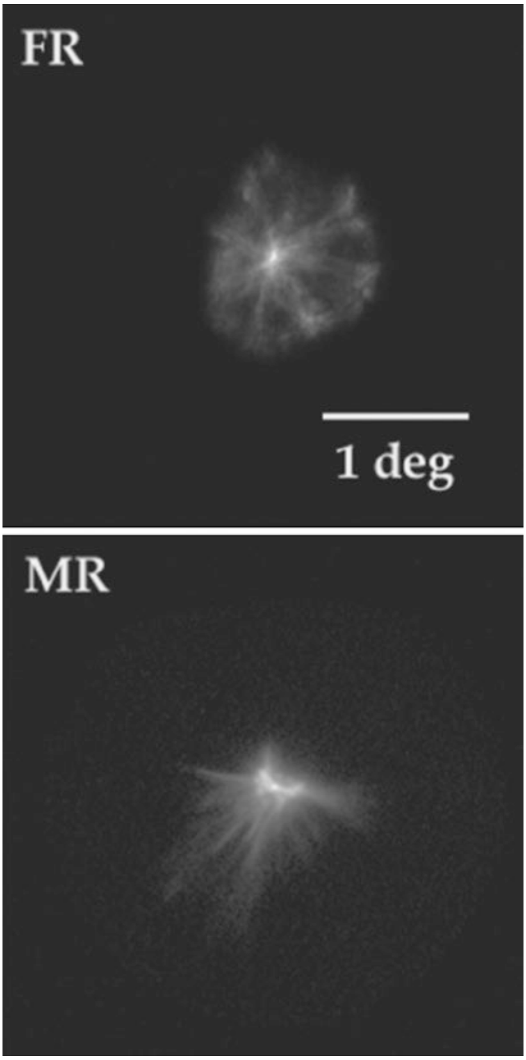


Fig. 42.54 Photographic record of aerial images reflected out from the retina of one eye of two test observers after exposure to a bright point-like Gaussian spot (from Navarro and Losada (1997), "Shape of Stars and Optical Quality of the Human Eye," *J. Optical Society of America* 14, n. 2, 355, Fig. 2. Permission requested)

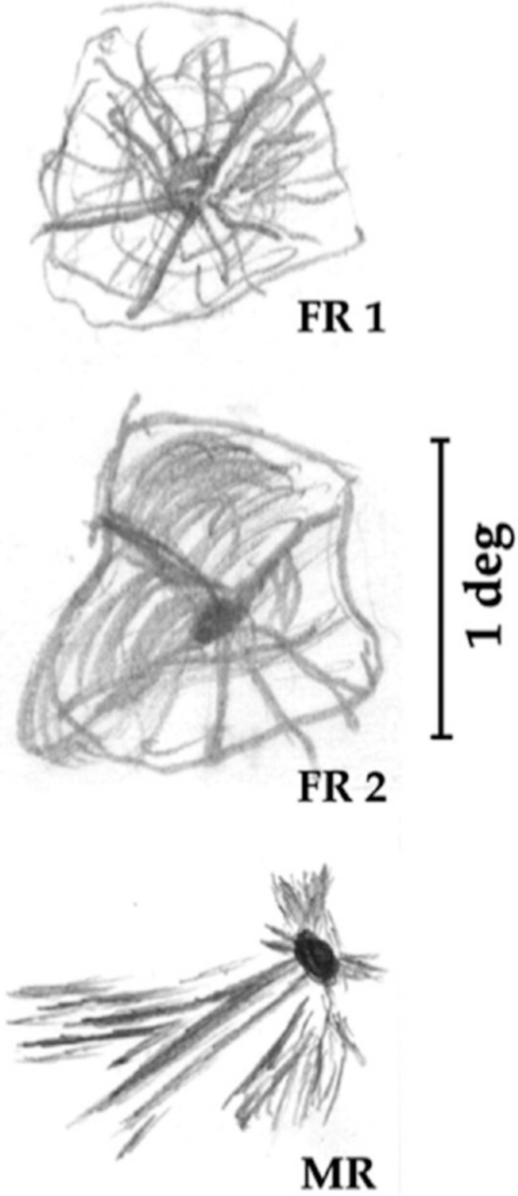


Fig. 42.55 Drawings of subjective star images by same observers whose aerial images were recorded (from Navarro and Losada (1997), 356, Fig. 3. Permission requested)

tric power—with size increasing with myopic defocus from positive power (p. 357). Notice that the evidentiary significance of the match relies on close agreements between quantitative features associated with the images.

8. The authors make a judgment of "close agreement" and "striking similarity" between objective and subjective patterns for each individual eye (ibid.). Notice the difference between the agreement between the subjective and photographic objective images here and, for instance, Bull's judgments of agreement and similarity with generic photographic analog simulations (Sect. 42.4).

9. The authors report the close match as supporting the explanatory hypothesis of the optical cause of the star images as entoptic phenomena, and declare the objective images evidence (ibid.).
10. On this basis, the authors consider the familiar, more specific potential explanation of star images in terms of intraocular diffracting structures or defects, namely, that "star images are caused by fibrous structures in the lens" (p. 358).
11. To motivate the hypothesis, they report that observers reported ray patterns only when the incident ray pass through positions away from the center of the pupil.
12. To test the hypothesis, they simulate the retinal PSF of a schematic eye model with aberrations and a hypothetical diffractive pattern of suture lines (ibid.) (Fig. 42.56). They consider the simulation a prediction.
13. They note the similarity with the objective photographs and the subjective drawings. They also note a difference in effect size (p. 359).
14. They take the difference in size to be explained by neglected correcting factors such as higher-order aberrations (compare Bull's similar reasoning).
15. They take the similarity to support the diffraction hypothesis (compare Bull's similar reasoning).
16. Rather than considering an alternative hypothesis, they conclude with another prediction based on the assumption of the diffractive explanation: different natural optical defects will result in different PSF patterns, and lens implants should result in the absence of star patterns (ibid.).

The different steps in the reasoning identify the new methodological role for different kinds of images–drawings, photographs, and simulation visualizations–in the new pictorial environment established by the computational regime: Photographic images provide objective evidence for an individual eye, computer simulations provide predictions and potential explanations, and subjective drawings provide the calibrating "ground truth." To illustrate the diversity of relevant pictures, and the methodological value of similarity between them, Navarro and Losada assembled a graphic composite of examples they labeled an artwork and titled "virtual sky" (Fig. 42.57).

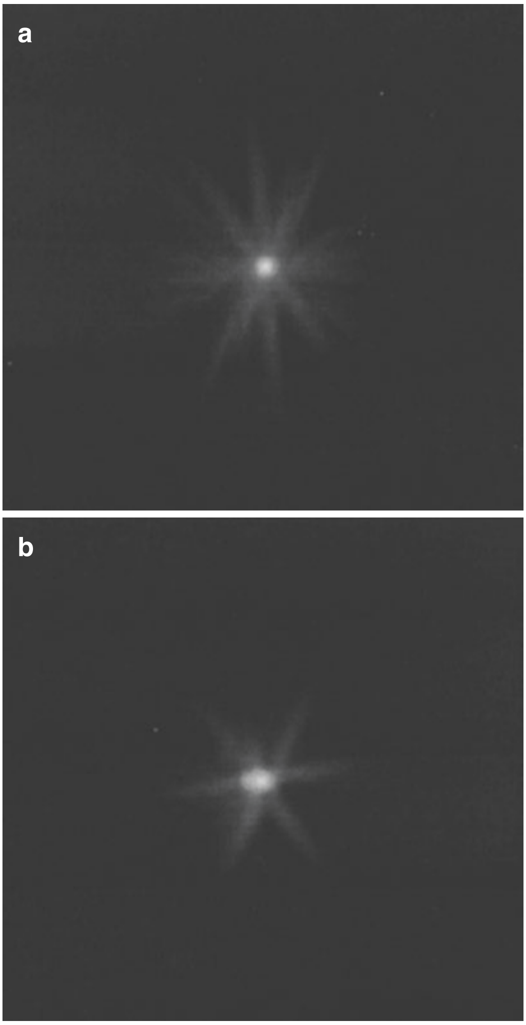


Fig. 42.56 (**a**, **b**) Result of computer simulation of the point-spread function from a bright point source encountering diffraction patterns in the virtual lens, with and without refractive aberrations (from Navarro and Losada (1997), 359, Fig. 7. Permission requested)

In a subsequent response, Xu and colleagues have compared psychophysical subjective reports of starbursts with computer models in order to support the optical hypothesis declaring dominant the explanatory role of uncorrected aberra-

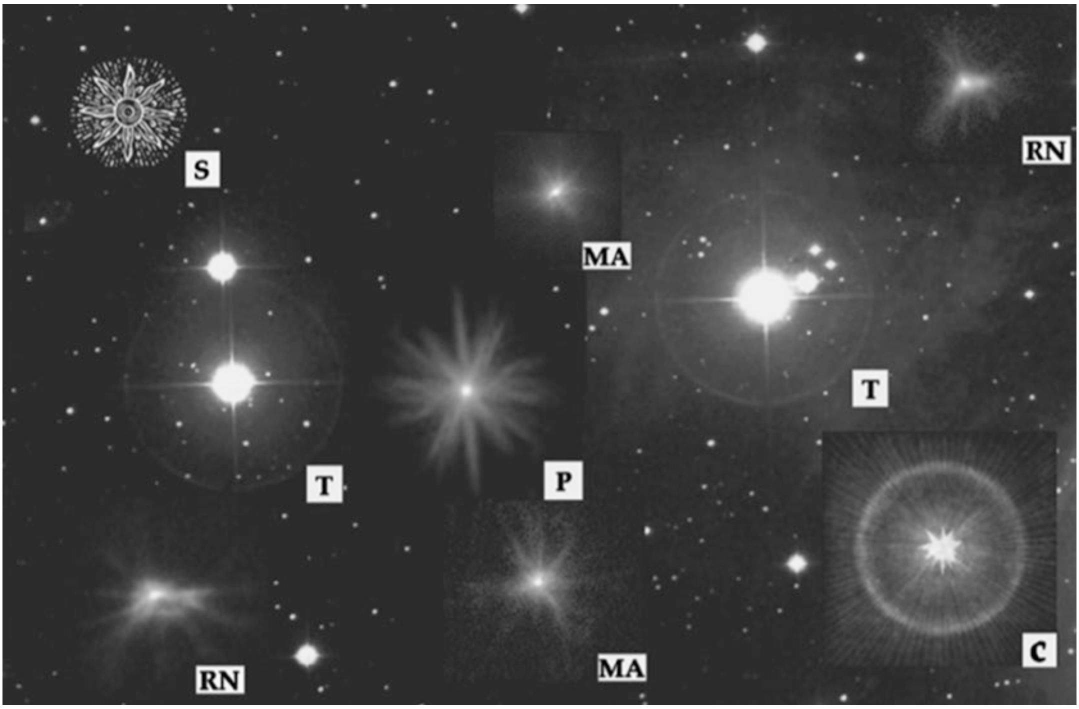


Fig. 42.57 Composite of star images in different kinds of pictures informing research into their optical explanation (from Navarro and Losada (1997), 354, Fig. 1 ("Virtual sky" artwork. Some stars in the original telescope image have been replaced by ocular images: T, original telescope images; S, symbolic representation; C, drawing of the subjective image of a bright point source[3]; P, prediction by our computer simulation. MA and RN experimentally recorded retinal PSF's). Permission requested)

tions, especially spherical aberration, myopic defocus, and pupil size [155]. More recently, the same authors have acknowledged that the explanatory aberration hypothesis is only tentative in the particular sense that the previous results do not undermine the role of diffraction defended by Navarro and Losada [155]. They follow Navarro and Losada proposal of testing the predictions of the diffraction hypothesis. In fact, they perform a sort of crucial experiment testing opposite predictions of two competing explanatory hypotheses, both about the specific optical origin of star images: diffraction and aberration [64]. Each hypothesis makes room for a minor role for the alternative cause.

The diffraction hypothesis predicts that starbursts are seen by individuals with a natural crystalline lens (including phakic eyes, with added intraocular lenses), with the diffractive fibrous structures, but not by individuals with replacement intraocular lens implants (pseudophakic eyes), or with individuals with apertures blocking the pupil center. By contrast, the aberration hypothesis predicts that phakic individuals seeing through an annular aperture that blocks the pupil center will see starbursts and that also will pseudophakic individuals with replacement lenses. Because pseudophakic lenses typically increase higher-order aberrations—which increase also with pupil size—but reduce lower-order ones, to those individuals, the starbursts will appear smaller.

Again, the experiment included a computer simulation exploring the different scenarios. A psychophysical experiment involved all individuals sketching drawings of the subjective star images. Individuals with phakic (addition), pseudophakic (replacement), and post-LASIK (lens surgery without addition or replacement) eyes were tested. All individuals reported seeing starbursts when looking at a high-luminance square quasi-point source against a dark background through a telescopic system with variable lenses and apertures. The drawings of perceptions through wedge apertures showed a correlation between the orientation of the aperture and the orientation of the star pattern. Drawings during the use of annular apertures showed the peripheral star pattern, incompatible with the diffraction interference hypothesis, and that the pattern of star images uniquely mapped onto the distribution of rays on the pupil.

The simulation played an experimental exploratory role with predictions that served a further testing function for causal hypotheses—it "explored the optical origin of the psychophysically observed starburst pattern" (p. 99). Software simulated ray-tracing to map the propagation and distribution of rays across the pupil, and computed the PSF with a Zernike polynomial approximation to the geometrical optics of the wavefront aberration. The different polynomial coefficients at different orders represent a measure of different aberrations. Again, the simulation visualization was produced, and its similarity or match was evaluated with the subjective drawings (Fig. 42.58).

The match, as in Navarro and Losada's earlier argument, relies significantly on the application of quantitative modeling in the production and interpretation of the images and the phenomena they depict. The approach lines up with the empirical and mathematical expression of the ideal of objectivity. As a result, the authors can claim that the match supports two roles for the simulations and the aberration hypothesis. It tests and supports the predictive power of the aberration model—it "confirms that the unique aberration of each eye can predict the unique properties of the starburst patterns" (p. 101)—and its explanatory power, the experiments support aberrations and not diffraction as the cause of selected features (ibid.).

The use of computer visualizations and other pictures in support of this particular hypothesis is part of a broader project of testing an objective approach for theoretical and clinical purposes. In a number of papers, Cheng, Bradley, Thibos, and colleagues have defended the use of polynomial approximations such as Zernike and Seidel forms of wavefront aberrations, or errors, as an objective and reliable method for predicting and ultimately replacing subjective judgments of image quality for different objective quality metrics [62, 63, 156]. Cheng and colleagues have also defended, for instance, that such polynomial terms can be reliable predictors for visual acuity measures, the "gold standard" of clinical determination of image quality ([156]: p. 300). For this purpose they performed a psychophysical experiment and a computer simulation.

I want to point out, for my own purpose here, their use of photographic simulations. The photographic images of test-types (from acuity scales) played the evidentiary role of calibrating benchmarks for the accuracy of the computational

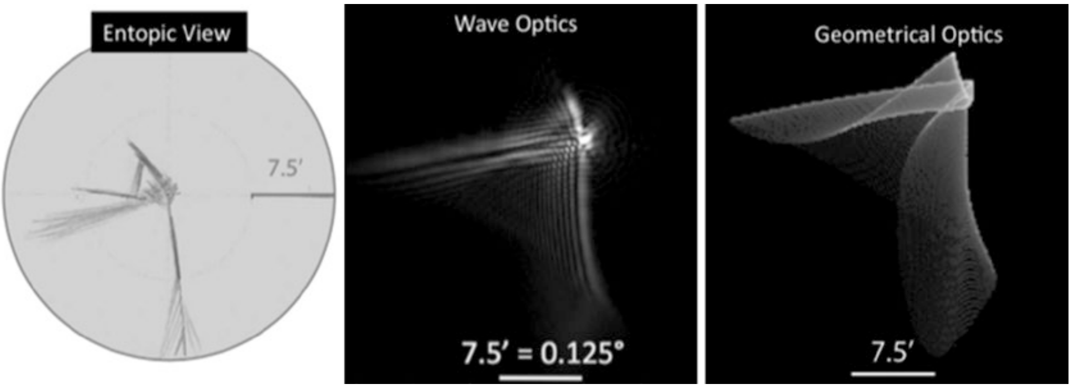


Fig. 42.58 Computer simulated visualization of optical models of starbursts (center and right) compared with drawing of subjective observation (left) (from Xu et al. (2019), "Psychophysical Study of the Optical Origin of Starbursts," *J. Optical Society of America A* 36, n. 4, B101, Fig. 7. Permission requested)

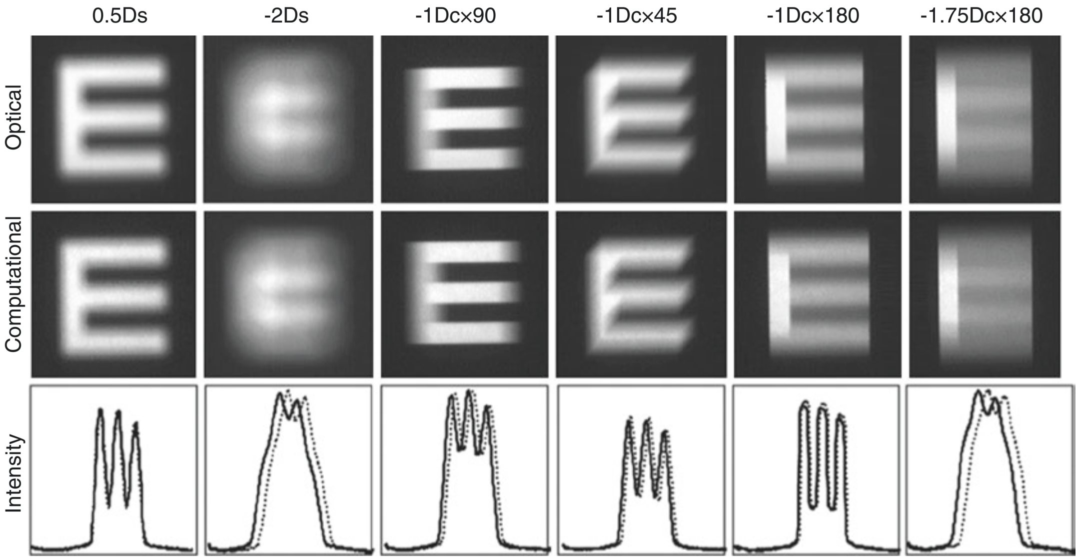


Fig. 42.59 Comparison of images of photographic and computer simulations of optical blur for testing the accuracy of the computational method (from Cheng et al. (2010), "Visual Impact of Zernike and Seidel Forms of Monochromatic Aberrations," *Optometry and Vision Science* 87, n. 5, 302, Fig. 2. With the publisher's permission)

method. In their words: "computationally blurred images were compared directly with optically blurred images" (p. 301). The CCD camera acted as a model retina (in an updated version of the eye-camera analogy). The comparison (Fig. 42.59) shows that "the results from the two methods were essentially identical for both spherical and astigmatic blur, thus confirming the accuracy of our computational methods" (Ibid.).

Here the photographic simulations of optical blur play one of the roles subjective drawings had played establishing the photographic standard. Neither kind of picture has been replaced by computer visualizations. Instead, computer simulations of blur still rely on them.

Once the objective technic or method has been declared reliable, such photographic and especially the validated computer images serve practical, clinical purposes, e.g., preparing or guiding a clinical intervention such as surgery and tracking the development of a patient's ophthalmic condition or recovery from a clinical intervention. The efficient generality and reliability of such techniques speak to the significance of the objective ideal.

The arguments I have been discussing based on simulations and pictorial comparisons are based on considerations of analogies. But the role of predictions serving testing purposes and providing evidentiary support for potential explanations indicates that the role of simulations in reasoning does not collapse into mere arguments by analogy. To higher or lower degree, they have provided inductive support for or against predictive and explanatory hypotheses beyond the heuristic function of suggesting them, that is, as instruments of "discovery." The methodological and technological standards for photographic and computer simulations have enabled experimental designs, lines of research, and sustained debates based on sharing them, also applying them critically and exploring their limitations.

In the case of the aberration model of subjective star figures, the commitment to this particular kind of optical explanation presents two aspects of both its realistic, physical, and causal interpretation and its descriptive accuracy. Here I can only point them out all too briefly and in passing. In the explanation, the model isolates one factor, a particular optical mechanism, and establishes as the central idealization. First, the accuracy of the model in its explanatory capacity ascribes to aberrations causal effectiveness in terms of the physical propagation of light in particular optical conditions in line with the terms of the idealization, independently of the impact of any other factor—and any interaction between them. Second, the use of Zernike polynomials to classify and predict aberrations places their mathematical description within a broader set of approximations, namely, a set of terms in an expansion series of the wavefront function. Explanation is not just predictive value: in what sense are the aberrations, as described mathematically in the series, isolated causally independent and effective parts of the physical propagation of an entity represented by the wavefront function? On what grounds does the physical, causal interpretation can be restricted to some terms and not to higher-order others that remain empty dangling descriptions? Different approximations raise different issues regarding the physical meaning and reality of their terms.[2]

What about the role of the different pictures in the use of computer simulations to explore and test hypotheses and explain phenomena? Computer simulations haven't replaced photographs or subjective drawings. Objectivity hasn't replaced subjectivity either in the targets of explanation and clinical correction or in the empirical constraints on the methodology of research. The working connection to the subjective information relies on objective mathematical models and material models, especially the pictures that can be publicly accessed, circulated, trusted, and used. Of course, as I keep reminding the reader, the epistemic role of the objective pictorial information ultimately requires each experimenter's own visual perception and, therefore, unavoidably rooted within what I call the subjective circle. Now, it is worth distinguishing the more practical project from the theoretical ones and acknowledge that, in matters of standards, a widespread call for objectivity has prioritized the procedural, technological objectivity, the one that would characterize and facilitate, over the general population, clinical tasks such reliable examination, diagnosis, and correction. Nevertheless, establishing the relevant kinds of techniques involves the application of predictive and explanatory models, and, as I have been indicating, those resources are the products of empirical research whose methodology depends on engaging subjective phenomena and information. Through chains of assumptions, computations, and manipulations, the pictures aim to represent, understand, and manage the subjective experience of blur. What I have shown is that the pictures of blur are of different kinds and have come to play different roles rather than being replaced.

42.6 Conclusion

I have identified and examined a cluster of interconnected mathematical and pictorial models and practices to characterize and to treat blur in eye vision. Along the way, I have tracked a tradition with dwindling but sustained interest in the visual representation of blur and its different research and clinical uses. Perhaps more surprising is how this phenomenon of visual indeterminacy is at the heart of a methodological, epistemic, and clinical challenge to strike a balance not just between the particular and the general, individuals and population—these are after all the constitutive challenge of much empirical science and all of medicine—but between the subjective and the objective. I have argued that the ideals and challenges distinguish clinical purposes from research projects, and yet the two are inseparable.

Does the interest in more objective and general mathematical models of optical blur and in more objective and illustrative visual pictures of individual blurred appearances have consequences for general research and individual treatment? Is there any role left for the individual experience of blur? I have argued that it is an inevitable part of the intersubjective character of the information and role provided by the use of

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[2] Consider the extreme case of Feynman diagrams, giving physical meaning to terms in an expansion of exact quantum field functions without the assurance that all those indicated separate phenomena are all real physical parts of the physical process.

pictures. It is also part of the calibrating and validating roles testing general optical models, research methods, and clinical tests and techniques. The confrontation of the individual application of the optical models and methods with subjective judgment, not just so-called subjective drawings, despite their potential unreliability, raises the issue of systematic differences between the optical models and actual individual experiences. The challenge consists in engaging this gap as an explanatory and clinical opportunity to identify the role of alternative factors. But this is also part of the intrinsic challenge of balancing the particular and the general in understanding and intervening. From a normative point of view, we can at least acknowledge the complexity and value of subjectivity and blur in perception and depiction as a research and clinical resource.

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Epilogue: The Future of Imaging

Antonio Pasquali

This extended and long excursion on the use of photography in medicine—which we hope has been stimulating and useful—cannot conclude without inviting our medical colleagues, humanists, after all, to a last and more general reflection.

The present book is about the use of the fixed image in a specific area of knowledge and practice: that of medicine; a mere corner, although very important, in the ubiquitous and ever-changing universe of still and moving images in which we are all immersed—a universe composed mostly of billions of inflated and ephemeral images, an iconic galaxy to which we are adapting ancestrally perceptual and conceptual behaviors at an inappropriate speed.

Half a century ago, maybe foreseeing how impressive this image irruption would become in the system of signs we handle, philosopher Jean Wahl forged the term *iconosphere* to refer to that world of always more refined and connotative signs of *images-things* that have come to complement—perhaps even with veiled intentions of replacement—the *logosphere* or reign of the *word-concept*.

The *word*, remember, is the temple of abstraction while the *image* is a facsimile of the empirical: whereas "house" refers to the general concept of a house, a house painted or photographed is always self-referential; it is only the specific and concrete house reproduced by the artist, painter, or photographer. The dialectic of the *iconosphere* with the *logosphere* is today in effervescence; it is far from a sensible and pacified coexistence and far from the reasonable complementarity that will come. Certainly, the image advances without ceasing and the cultured use of the word recede to a reduced speech in certain social strata which according to linguists reaches around 300 terms.

The image has become a communicative necessity, and the search for a new verb-icon equilibrium now appears in all cultural estates: today nobody would buy tourist guides or gastronomic recipes like those that our grandparents bought, without images.

Medicine, its research, academy, practices, and conservation processes do not escape this turbulent rearrangement of our expressiveness, its codes and signs. The dialectic of the *Lógos* or *Verbum* and the *Icon*—that is to say, the dialectic of the word and the image—is nonetheless happily beginning to move toward complementarity rather than competitiveness, mostly because both expressive forms have exclusive expressive powers as well as an Achilles heel.

Everyone comprehends or intuits that no image would serve to codify iconically the Kantian concept of a priori form of understanding, and that no verbal description of the Baroque Chapel of the Rosary of Puebla could convey the reality compared to a Polaroid snapshot. This was already clear to Leonardo in the fifteenth century: in one annotation placed on the side of one of his Codices' anatomical drawings of the heart reads: "*How could you describe this heart in words without filling a whole book? The more*

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minutely you try to write of it the more you confuse the mind of the listener."

The praise to the former can be found a century later in Galileo. He reminds in *The Dialogue Concerning the Two Chief World Systems* (Dialogo sopra i due massimi sistemi del mondo): "*But surpassing all stupendous inventions, what sublimity of mind was his who dreamed of finding means to communicate his deepest thoughts to any other person, though distant by mighty intervals of place and time! Of talking with those who are in India; of speaking to those who are not yet born and will not be born for a thousand or ten thousand years; and with what facility, by the different arrangements of twenty characters upon a page!*"

It was written that medical sciences and visual arts would tend toward an intensive use of iconic codes and, as the reader will have noted, that the history of their development has been fascinating, from the first fanciful engravings to the still or motion images that medical communications use abundantly nowadays.

If we celebrate the complementarity of word and image both in literature and medical academy—a communicative virtue that authors and editors of these specialties should cultivate—it is because a serious attempt to consider that "*the word-concept only knows how to name what was previously perceived*" has already occurred in the recent past (and could happen again in the future). The *icon* and, more in general, what is perceived, always precedes the *logos*, and this could give rise to a type of thinking, expressing, and communicating facts with only images, since "*all visual perception is already a cognitive activity*."

As a modest example of this communication using only images, we could take two millennials wanting to communicate by using only emoticons raised to the highest degree of refinement (Samsung already states on its website that "*8 out of 10 users communicate daily through images*" … and that "*image is a new language where the main channel is the smartphone as universal device that has modified the communication habits of people*"). This interchange of images was thought and proposed by a very enlightened, singular and long-lived thinker of our time, Rudolf Arnheim (1904–2007), a German-American Gestalt psychologist who spent his life analyzing the role of the fixed and moving image. He became famous in 1938 when he suggested an apparently reactionary paradox: the speaker, he said, had fallen like a bomb on the cathedral under construction of the silent cinema, destroying it, because the mute was trying, successfully, to narrate and express always more complex things by using purely iconic signs, only visual elements and no words (and that is why it was an art); the arrival of the soundtrack degraded the role of the purely visual.

Arnheim, Leonardo's great disciple, constantly exalted the kinship between Science and Art. In 1969, he published his main work whose mere title is a whole program: *Visual Thinking*. The scholastic philosophic sentence *nihil est in intellectu quod prius non fuerit in sensu* (nothing is in the understanding that was not earlier in the senses) embodies Arnheim's concept that all visual perception is already in itself a cognitive activity, even before receiving the endorsement of reason. This was pointed out by Arnheim in an attempt to re-dignify the icon and the iconic discourse as self-sufficient code of communication.

His doctrine still deserves consideration if only to recover the dignity of the iconic in a world that tends to change in quantity and profanity the intrinsic quality and sacredness of the image or to weigh the arguments of those who fear—not without reason—an intellectual collapse of *Homo sapiens* by his progressive abandonment of the word and reading.

Let us add, apart from the above, that the dignity of the icon is also threatened: the increased easiness of this electronic age and the trivialization of the algorithms applicable to post-production allow the simple aesthetic retouching of the image or the "photographically impossible effects," as well as the innocent alteration of details and the authentic fake picture. All these are heavy interventions on the image which those interested—and with intellectual honesty in scientific analysis and disclosures—should avoid; they should, in fact, adhere to the old virtue of translators, the *akríbeia* or accuracy, which prescribes restraining to "Everything, Only and How" (literally, accuracy, precision). All this, not to mention the contribution that the image has had to our progressive loss of privacy, by being captured and preserved by all kind of controllers: security, advertising, police forces, medical world, anti-terrorist fight, insurances, border controls, and others, by means of increasingly sophisticated software like the ones used in current facial recognition.

Another general issue of great relevance to anyone interested in the use and conservation of iconographic material concerns the lifespan of the different physical supports for storing images, an issue on which the related industries prefer to keep a suspicious silence given a rather daunting reality.

Those who have had the luck to visit monumental ruins in their discovery phase—in Egypt or other places—may have observed that, next to the reporters, archaeologists and researchers of diverse disciplines trying to reproduce every square centimeter of what came to light, and next to a panoply of the most modern photographic, cinematographic, and TV equipment, there was a more silent group of pencil and brush artists drawing on high-quality paper all relevant objects left from the excavations. The explanation they always give is the same: "In a few centuries everything else will be deleted, only our drawings will remain." From the cavemen to today, from the petroglyph to the photosensitive emulsions and bits, we have done nothing but sacrifice the supports lifespan, all for the sake of quality, quantity, reproducibility, and communicability; the rapid aging laboratory systems used today do not yield scientifically precise results in this area.

The problem with the supports lifespan was clearly posed for the first time in the thirteenth century, when paper was becoming available and cheaper. The Holy Roman Emperor, Federico II de Hohenstaufen, banned through an edict dated 1.231 the use of paper for notarial documents, believing it to be less permanent than the old leathery parchment or vellum. The international standards ISO 9706 and ISO 11108 today codified the characteristics of "permanent paper" and "archival paper" as only made of cotton, linen, or hemp fibers; their lifespan ranges between 60 and 300 years. Only Korean Hanji paper from mulberry pulp is guaranteed to last for 1000 years; the "acid paper" from which newspapers are made only lasts 30–40 years. Since 2005, the United Kingdom Atomic Energy Authority (UKAEA) intends to keep its secret documents for at least 30 centuries by transcribing them into sheets of improved papyrus, sealed in copper envelopes and stored in an atmosphere identical to that inside the Egyptian pyramids!

With the exception of some orthochromatic films, most photographic and cinematographic emulsions existing today will turn magenta, have fungi, or chemically decompose in little more than a century. The possibility of digitizing all analogue material made us believe for a short time that technology had achieved the eternal storage of the message in any of its various presentations.

A report of the French Academy of Science and Technology dated from March 29th, 2010, on *Longevity of Numerical Information* wipes out this illusion: "*All digital media lasts in good condition between 5 and 10 years … CD and DVD, flash memories, magnetic tapes and blue-ray are constantly degraded even if they are not used …*" Important institutions dedicated to digitize their heritage are programming a policy of "perpetual migration" from one digitization to the next, which will inevitably lead to a loss of information with each migration.

We are conquering Space and its cosmic depths but not Time: our spaceships travel through the universe but we are unable to master the temporal dimension. The North American semiologist, T.A. Sebeok, demonstrated in 1984 the absolute impossibility to have a message sent today received by humanity in 20,000 years.

What future awaits the fixed image and the cinematographic one in general? Regarding the medical image, a communication from the 96th Congress of Radiology Society of North America (RSNA) in 2010 prudently pointed to an upcoming merger of different imaging techniques without commenting on further futures. Current technologies, such as *Volume* and *Cinematic Rendering*, have gone in that direction.

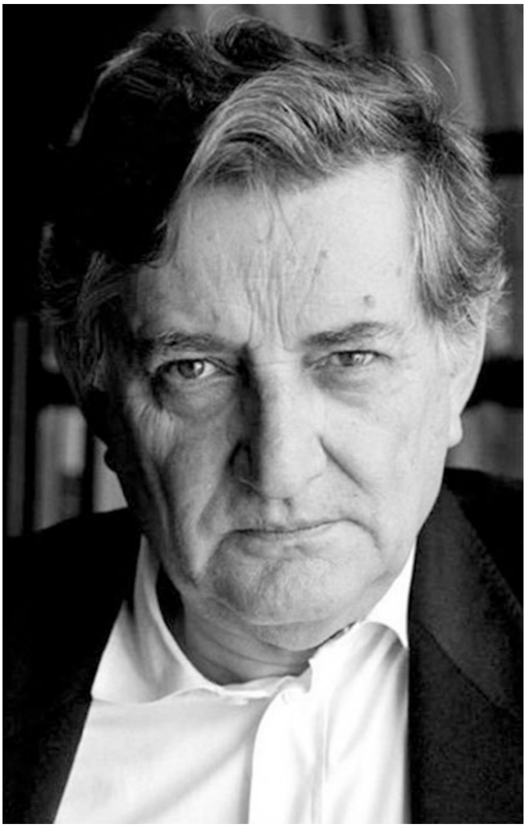
The high-quality clinical image is already been used to generate diagnostic algorithms. We are at the beginning of a profitable human-machine relationship that will end up modifying the doctor-patient relationship with the gradual replacement of the patient by an image. The doctor will work more and more on iconic material, and this will guarantee an important future for telemedicine.

The next important issue consists of the creation of large medical data bases that allow to generate new diagnostic algorithms, a technological progress that will not fail to pose deontological and guild problems to the medical profession.

As for the icon in general—the image in its broadest sense—any attempt at forecasting could be a serious imprudence. Within 50, 100, or 200 years our descendants will look back at us with the condescending look comparable to the one we use to look at the medicine that crushed pearl powder, cooked bats, and applied leeches. They will smile when imagining us botching with tiny mega- and gigabytes or traveling at subsonic speeds on vehicles on iron rails, but with a meaningful difference: they will have to do very little or none to imagine us as we are leaving them in inheritance billions and billions of silent and sonorous images, an advantage that we did not have from our past, which has a scarcity of icons—prior to the advent of photo-cinematography—and possibility to reproduce images and its convertibility into pulses and transmissible codes.

From which angle, with which unprecedented analytical and communicative capacities will they look at us? This is not possible to imagine. How to foresee the next and most distant decisions of the great communication laboratories, of media manufacturers, computer science, cybernetics and robotics, and even the unexpected surprises like the Internet—daughter of Arpanet, a military device from the Cold War—which gave us all the capacity to emit and re-democratize communications?

In what newest supports will the images be fixed, how will they be stored and communicated? Will they be part of a common heritage or patented merchandise for sale? Will *Word* and *Image* continue in their current state of complementarity or will the iconosphere imagined by Arnheim our next future second language? And, just widening the circle of probabilities, what will become of us as people, as citizens, and as patients in the near future when the *artilects* (artificial intellects)—children of an anomic, insensitive, and amoral artificial intelligence—will be in charge of carrying genetic engineering and biotechnologies to their ultimate consequences? Will we then be allowed to continue designing better worlds or will there only be room for dystopia, for that probability evoked in 1948 by the patriarch of cybernetics N. Wiener, according to which medicine will be responsible for programming our death to maintain homeostasis of the social body? The least erroneous way to predict a desirable future is to imagine, plan, and begin to build it at once.



In Memoriam

Antonio Pasquali (1929–2019)

> *I prefer a thousand times to live thrown into the future, and - instead of debasing myself sapping the orchard of memories or filling photo albums- take full time responsibility for the world that I will leave to my successors.*

Father of the editor Paola Pasquali, Prof. Antonio Pasquali was a former Assistant Director General for Communications in UNESCO and professor of ethics. As a virtuoso of thinking about his time and glimpsing the future, he has authored an extensive and dense work. Philosopher and humanist, his reflections cross the fields of philosophy, culture, and communication, with eternal intellectual anguish about the future of humanity and human coexistence. Antonio Pasquali leaves an important legacy to the new generations.

He did not live to see this book published.

The book is dedicated to him, a man of the future.

Glossary

Advanced Persistent Threat, APT It is a lengthy prolonged cyber-attack in which the intruders gain access and remains undetected for an extended period of time.

Afocal photography It is a method of photography where the camera with its lens attached is mounted over the eyepiece of another image forming system such as an optical telescope or optical microscope, with the camera lens taking the place of the human eye.

Angle of vision It is defined by the focal length of a lens. For a given sensor size, the shorter the focal length, the wider the viewing angle and the longer the focal length, the narrower the viewing angle.

Apo lens It is a high quality lens that eliminates or minimises APOchromatic or 'rainbow-like' aberrations at the edges of objects.

ASPH lens It is a high quality lens that eliminates or minimises ASPHerical distortions.

Autofluorescence The naturally occurring fluorescent emissions from a specimen without the introduction of fluorescein dye.

Autonomy or self-determination (Ethics) Refers to the individual's right to independent decision-making without coercion.

Bayer filter array The pattern of red, green and blue coloured filters overlaid on top of the pixels on a typical CCD or CMOS imaging sensor. There are twice as many green filtered pixels as red or blue to mimic the sensitivity of the human eye.

Blacklight A visually very dark, or black light source which emits short wave blue light and/or long wave UV radiation. They have many applications including producing fluorescence in night clubs, mineral prospecting, and attracting moths at night.

BMP It is a fil formatalso known as bitmap image file or device independent bitmap (DIB) file format or simply a bitmap. It is t used to store bitmap digital images.

Cataract The thickening and clouding of the natural lens of the eye.

Category 1 Images (forensic) Images taken for documentation purposes, i.e., to preserve the appearance of evidence.

Category 2 Images (forensic) Images taken for examination purposes, i.e., to be used for later comparisons to a known item. (e.g., Fingerprints, impressions, blood spatter)

CCD sensor Sensor that detects and transmits information used to make an image.

Centers for Medicare & Medicaid Services (CMS) A federal agency within the United States Department of Health and Human Services (DHHS) that administers the Medicare program and works in partnership with state governments to administer Medicaid, the State Children's Health Insurance Program (SCHIP), and Health Insurance Portability and Accountability Act (HIPAA) standards.

Chemiluminescence The emission of light during a chemical reaction.

Choroid The outer vascular layer of the eye between the sclera and the retina.

CIA Triad It is a concept known in cyber and information technology (IT) circles which refers to the confidentiality, integrity, and availability of digital information.

Colonoscope Exploration of lower GI tract with digital endoscope.

Color constancy Is the phenomenon that ensures that the perceived color of objects remains relatively constant under varying illumination conditions. It is a subjective phenomenon.

Confocal An optical system using a special pinhole at the imaging foci to block out-of-focus imaging rays for increased contrast and resolution.

Convolutional Neuronal Network It is a type of artificial neuronal network designed for pattern recognition that combine multiple layers of representative learning with deep architecture. They extract features from data, creating an association that best correlate to a diagnosis.

Cornea The front optical surface of the eye responsible for the highest refractive power of the eye.

Corneal endothelium The single layer of cells lining the posterior surface of the cornea.

Cross polarized The usage of two polarizing filters, where one is placed on the light source, and the second on the camera lens, with the filters orientated at 90° to each other. Used to eliminate specular reflection.

Current procedural terminology (CPT) Is a medical code set that is used to report medical, surgical, and diagnostic procedures and services to entities such as physicians, health insurance companies and accreditation organizations.

Cyber security Measures taken to protect digital information from unauthorized access or attack.

Data encryption Refers to the practice of converting the data into an unrecognizable format or code in such a way that only those authorized to 'decode' and view the data can do so.

Depth of field, DoF It is the range, or linear distance, in front and behind the point of focus (PoF) that appears sharp.

Dermoscopy In vivo technique based on the use of a skin surface dermoscope that allows the evaluation of structures correlated to histologic features.

Diaphragm (optics) A thin opaque structure with an opening at its corner. It controls the lens aperture and therefore the light entering the lens.

Digital zoom Enlarged crop of the image.

Echoendoscope On same instrument digital endoscope probe linked with ultrasoning examination.

Electronic Medical Record (EMR) A computerized database that typically includes demographic, past medical and surgical, preventive, laboratory and radiographic, and drug information about a patient. It is the repository for activenotations about a patient's health. Most EMRs also contain billing and insurance information and other accounting tools.

Endoscopy Procedure that allows the inspection of internal organs.

Enteroscopy Endoscope design for small bowel examination.

ePHI Electronic protected health information.

Ethics Are the guiding principles which help the individual or group to decide what is good or bad.

Exposure Amount of light which reaches the camera sensor or film.

Fiberscope Endoscope built with fibers since 1990 replaced by digital sensors.

Figure legend Information about the picture.

Fisheye lens A camera lens whose viewing angle is extremely large, 180° or more.

Fluorescein angiography The use of fluorescein dye injected into the vascular system to record retinal circulation.

Fluorescence The visible or Infrared light emitted as a result of a material being irradiated with a shorter wavelength light such as Ultraviolet light.

Fluorescence light The visible light emitted when a substance is excited by UV radiation.

Frankfort line Line joining the lower orbital rim with the external auditory canal.

Full spectrum camera A digital camera whose sensor has been converted so that it is capable of recording UV, visible and IR wavelengths.

Fundus photography Photography of the posterior pole of the eye, usually in color.

Gamma adjustment Non-linear adjustment of an image brightness on the digital screen.

Gastroscopy Exploration of upper GI tract with digital endoscope.

Generative Adversarial Network Refers to generative algorithms comprised of two deep neuronal architectures contesting against each other. This process of learning with a generator and discriminator contributes toward meeting the need for synthetic data augmentation.

Glaucoma Increased intraocular pressure causing optic nerve damage.

Hot mirror filter A filter placed over the front of an imaging sensor at the time of manufacture to absorb both UV and IR, to enable cameras to give the "correct" colour when used for conventional photography. A hot mirror filter can be used with a full spectrum converted camera to enables it to record "correct" colours.

Image cropping Removal of unwanted areas of the image.

Image resolution Measure of how much of a detail an image has.

Imaging chain Refers to the sequence of events that occur from the moment the image is acquired until the moment the image is interpreted by a viewer.

Indocyanine green A water-soluble dye which fluoresces in the near-infrared range of 790–805 nm.

Information system Refers to the infrastructure (typically hardware and software but sometimes also organizational and/or personnel) components that collect, process, store, transmit, display, disseminate, and act on information.

Infrared (IR) light Electromagnetic radiation with a wavelength longer than that observed for red light, from 700 nm up to about 1 mm.

Infrared windows Refers to a property of the earth's atmosphere that lets some infrared radiationpass directly to space without intermediate absorption and re-emission, and thus without heating the atmosphere.

ISIC archive The International Skin Imaging Collaboration archive is an open access free online database that includes tens of thousands of dermatological images, both clinical and dermoscopic, from leading centers around the world.

ISO These are the initials of the International Organization of Standardization that issues standards covering almost every industry. In photography, ISO refers to the sensitivity of the camera sensor to the incoming lightdevises to camera sensor sensitivity.

Lens barrel Tube containing the elements of a lens.

Luminol A reagent used to detect trace amounts of blood.

Machine learning A subfield of artificial intelligence that studies how computers can learn tasks without being explicitly programmed to conduct them. A broad branch of computer science involving methods that enables machines to make predictions and learn automatically from experience. It encompasses from the simplest linear.

Magnification ratio/reproduction ratio of a macro lens Reproduction ratio is defined as the size of the subject relative to the image on the film.

Memory card It is a small, flat flash drive used especially in digital cameras and mobile phones. They come as microSD, Compact Flash, XQD and CFast.

Metadata A text-based information that describes the image.

Michelson interferometer Utilizing a beam splitter, the light source is divided into two beams, one of which is a reference beam, the second of which is directed at an object or sample. The beams are then recombined, producing an interference pattern which produces the image.

Microbolometer It is a specific type of bolomer used in thermal cameras. A bolometer is a device made of an absortive element connected to a thermal reservoir through a thermal link. Its function is tomeasure the power of incident electromagnetic radiation via the heating of a material with a temperature-dependent electrical resistance.

Minimum focusing distance The minimum focus distance is the shortest distance at which a lens can focus. In the case of DSLR Cameras, the distance to the subject is measured from the focal plane mark on the camera body, not from the front of the lens.

Moral Refers to the beliefs of the individual or group as to what is right or wrong.

Multi-factor authentication, MFA It is an authentication method in which a computer information system user is granted access only after successfully presenting two or more pieces of evidence of identity and authority to access the information.

Mydriatic dilation Usually with pharmacological agents to induce dilation of the pupil.

NBI (narrow band imaging) Optical filter (narrow blue and green) that allow better superficial digestive mucosa examination.

Near infrared region The near-infrared region of the electromagnetic spectrum is the one that extends from 780 to 2500 nm.

Noise It refers to visual distortion. The noise looks like little pixels of color or spots on your picture.

Nonmaleficence In ethics, it is to do the least harm possible to reach a beneficial outcome.

Non-mydriatic dilation Allowing the natural dilation of the pupil through dark adaptation.

Optical coherence tomography An instrument using coherent light to produce a cross section image of the retina.

Optical zoom Uses the optics (lens) of the camera to bring the subject closer.

PACS Picture archiving and communication systems, is a storage system which substitutes manual search, filling of information and transport of images.

Photomicrography Photographing through a compound microscope.

Pixel It is the smallest independent semiconductor element that can absorb photons and liberate electrons.

Plenoptic light Relates to all the light travelling in every direction in a given space.

Plenoptic or light-field camera It is a camera that captures information about light emanating from a scene, both its intensity and direction. Conventional cameras only record light intensity.

PNG Acronym for Portable Network Graphics. It is a raster-graphics file-format that supports lossless data compression.

Prosumer cameras It is a camera that fill the niche between the basic compact camera and the more advanced SLR (single lens reflex) cameras. The word Prosumer comes from an amalgam of the words ‘professional’ and ‘consumer’.

Quantum Generative Adversarial Network Quantum computing uses the power of atoms to perform calculations and manipulate data. In Quantum generative adversarial networks, the data either consist of quantum states or of classical data and the generator and discriminator are equipped with quantum information processors. They may exhibit an exponential advantage over classical adversarial networks.

Raster or bitmap image It is a dot matrix data structure that represents a generally rectangular grid of pixels (points of colour). They are stored in image files with varying formats.

RAW A camera raw image file, also called “digital negative”, is the format that contains minimally processed data from the image sensor. They are unprocessed images.

Resolution Number of points that make up the image; the amount of details that the camera can capture.

Retina The inner layer of tissue containing photoreceptors at the back of the eye.

Retinal pigment epithelium The pigmented layer between the retina and the choroid which provides a physical and optical barrier between them.

Ring-flash It is a compact electronic flash attached to the front of a lens, usually for close-up photography.

Soft box A light modifying attachment placed on studio flashes to soften the light intensity output, accessory that allows to soften the light of a flash placed inside, making it more diffuse and directional.

Solid-state detectors It is a detector in which a semiconductor material (silicon or germanium crystal) constitutes the detecting medium.

Store and forward (telemedicine model; asynchronous) Term describing store and forward transmission of medical images and/or data because the data transfer takes place over a period of time, and typically in separate time frames. The transmission typically does not take place simultaneously.

Teleconverters They are precision optical accessories that can be mounted in-between compatible lenses and the camera body. Teleconverters increase the focal length of the primary lens and can produce a shorter working (object) distance as well.

The Internet of Things, IoT Describes the global digital network in the modern world. It is the extension of Internet connectivity into physical devices and everyday objects. These devices can be remotely controlled and monitored.

Thermal imaging A method that collects infrared radiation from objects in the scene and creates an electronic image.

TIFF Acronym for Tagged Image File Format. It is a computer file format for storing raster graphics images.

Ultraviolet (UV) light The region of the electromagnetic spectrum from around 10 to 400 nm, with the region from 300 to 400 nm being used for imaging purposes. It is usually divided into UVA (315–400 nm), UVB (280–315 nm), and UVC (100–280 nm).

Videodermoscopy Storing dermoscopic images before surgical excision and for monitoring a suspicious lesion (sequential digital dermoscopy).

Vidicon tube (later substituted by the CCD sensor) It is a storage-type camera tube, a type of cathode-ray tube used as the sensing element.

Virtual Private Network, VPN It is a technology developed to allow remote users to securely access corporate remote applications and resources. To ensure security, it has requires authentication methods, including passwords or certificates, to gain access to the VPN. A VPN enables users to send and receive data across shared or public networks as if their computing devices were directly connected to the private network.

Visible light The range of wavelengths visible to the human eye. Thought to range from approximately 380 to 740 nm, it overlaps slightly with longer wavelength UV and short wavelength IR light.

White balance It is the global adjustment of the colors to render specific colors—particularly white color—correctly. Making white look white. It refers to the setting on camera for calibrating the prevalent quality of illumination. The WB informs the camera of the colour temperature of the light when an image is captured for ensuring correct colour rendition without unwanted colour casts.

Index

P. Pasquali (ed.), *Photography in Clinical Medicine*, https://doi.org/10.1007/978-3-030-24544-3