# Understanding Color

8

Oriol Yélamos, Rafael Garcia, Brian D'Alessandro, Mani Thomas, Sachin Patwardhan, 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

O. Yélamos
Dermatology Department, Hospital de la Santa Creu i Sant Pau, Universitat Autònoma de Barcelona, Barcelona, Spain

Dermatology Department, Centro Médico Teknon - Quirónsalud, Barcelona, Spain

R. Garcia
Computer Vision and Robotics Group, University of Girona, Girona, Spain

B. D'Alessandro · M. Thomas · S. Patwardhan
Canfield Scientific Inc., Parsippany, NJ, USA

J. Malvehy (✉)
Dermatology Department, Hospital Clínic, Institut d'Investigacions Biomediques August Pi i Sunyer, Universitat de Barcelona, Barcelona, Spain

CIBER de Enfermedades Raras, Instituto de Salud Carlos III, Madrid, Spain



P. Pasquali (ed.), *Photography in Clinical Medicine*, https://doi.org/10.1007/978-3-030-24544-3_8

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

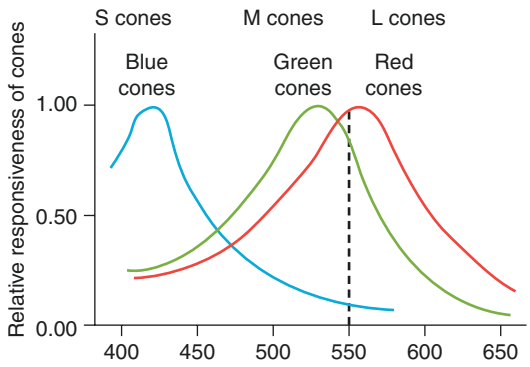


**Fig. 8.1** Relative responsiveness of cones. (Image available at: https://i.stack.imgur.com/fNRcL.jpg)

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.

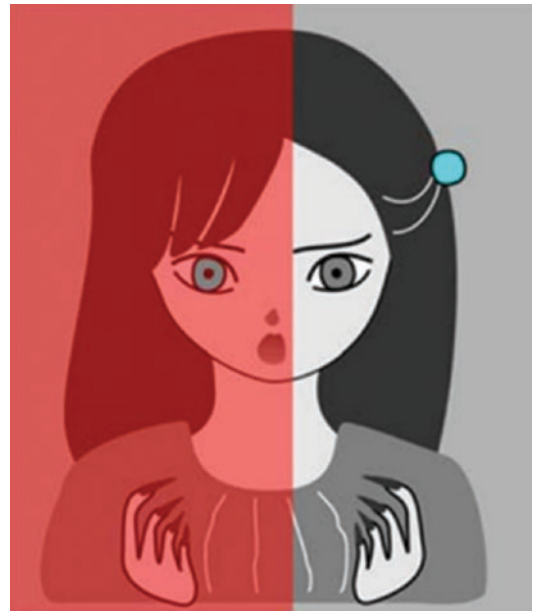

**Fig. 8.2** Examples of color constancy. In this image, the color of the right eye is the same as the left eye (gray). However, due to the application of a superimposed filter, the color of the left eye appears blue. This example helps understand why some lesions may look blue on the skin. (Adapted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

## 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-

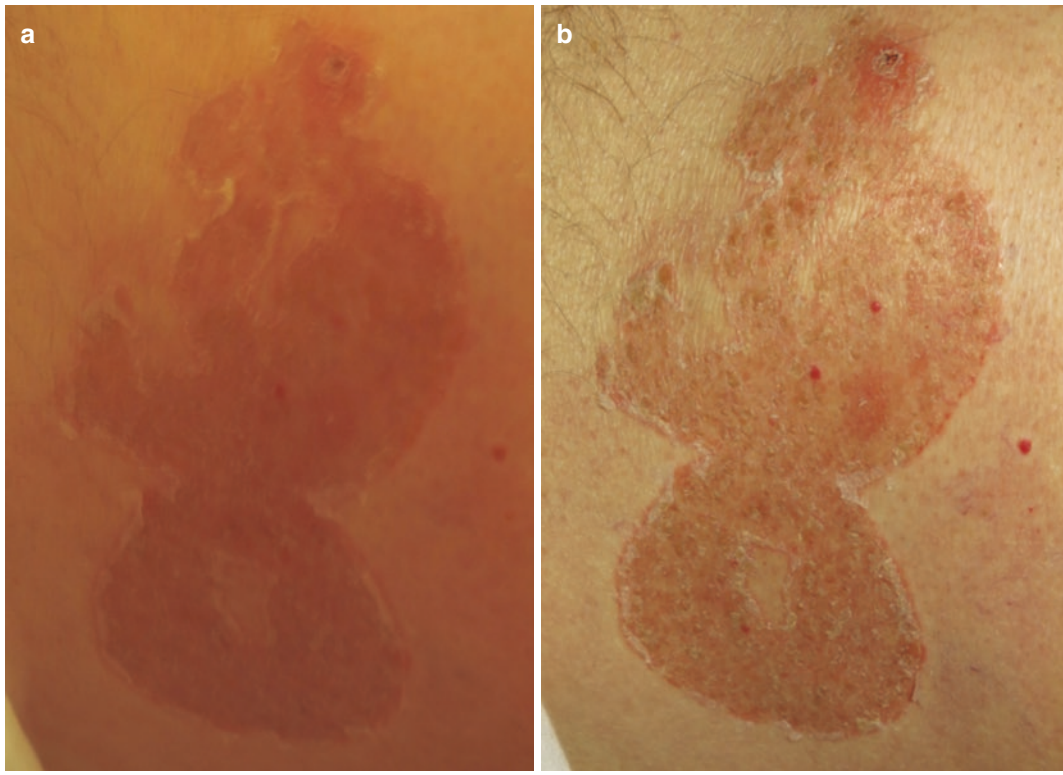


**Fig. 8.3** Impact of illumination on clinical photography. Picture (**a**) was taken at f/5.6, 1s without flash, whereas picture (**b**) was taken at f/5.6, 1/60s with flash light. Note that the color tone is more vivid in the picture using flash light, better showing the details of this example of 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

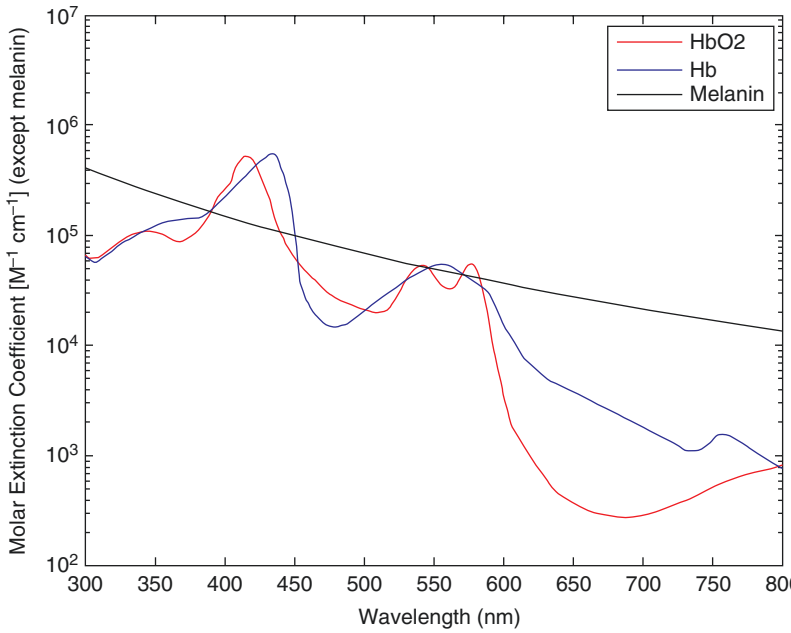


**Fig. 8.4** Absorption spectra of Oxyhemoglobin (HbO2), Deoxyhemoglobin (Hb), and Melanin

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

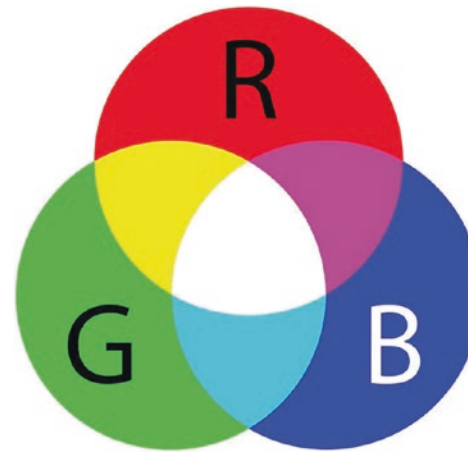


**Fig. 8.5** Schematic representation of the RGB color model

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.

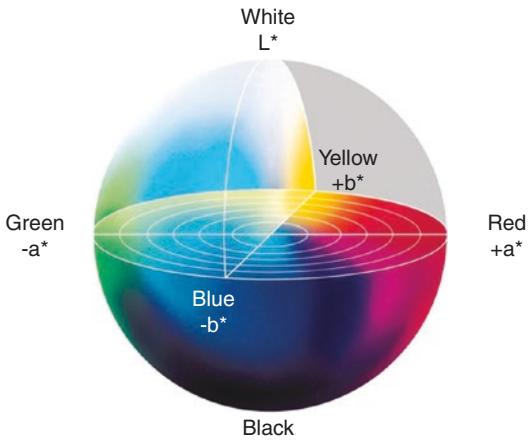


**Fig. 8.6** CIELAB color space. In this tridimensional model, $L$ defines the lightness of a color, $a^*$ defines the green to red axis, and $b^*$ the blue to yellow axis

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].

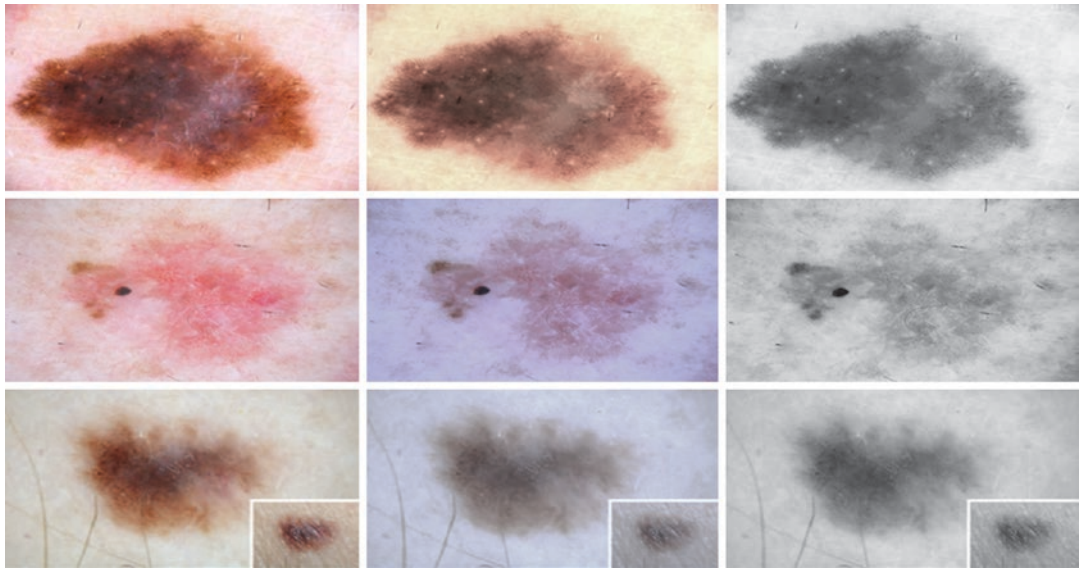

**Fig. 8.7** Examples of melanomas showing color variegation. The first column shows images using adjusted white balance, the second one using inadequate white balance, and the third one converting the images to gray scale. It seems that some structures are more conspicuous when using the gray scale 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)

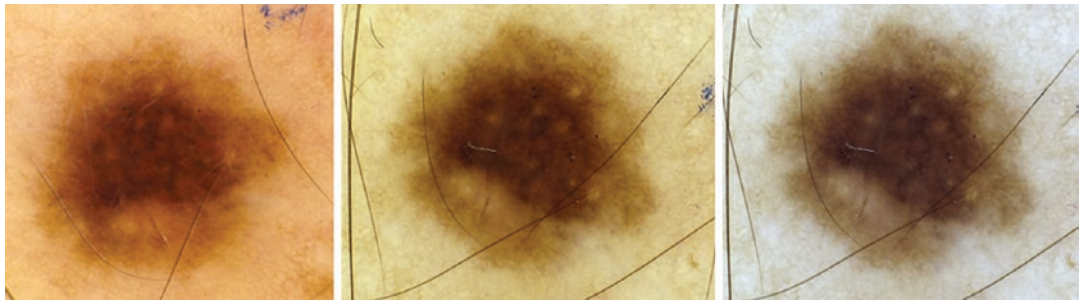

**Fig. 8.8** Examples of dermoscopic images taken with the same device over time. While the structures within the lesion remain stable, the color profile changes since the capture settings are dynamically adjusted by the camera software which averages the color in each acquisition. Although the clinical 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].

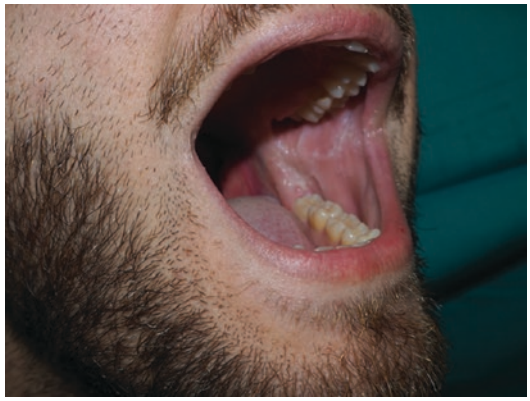

**Fig. 8.9** Generation of shadows when obtaining images from the oral cavity. Note that there is a shadow in the left upper quadrant of the mouth due to the location of the flashlight in the top part of the camera. This issue can be solved by using annular flashlights

### 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.

## References

1. Henning JS, Dusza SW, Wang SQ, Marghoob AA, Rabinovitz HS, Polsky D, Kopf AW. The CASH (color, architecture, symmetry, and homogeneity) algorithm for dermoscopy. J Am Acad Dermatol. 2007;56:45–52.
2. Argenziano G, Fabbrocini G, Carli P, De Giorgi V, Sammarco E, Delfino M. Epiluminescence microscopy for the diagnosis of doubtful melanocytic skin lesions: comparison of the ABCD rule of dermatos-

copy and a new 7-point checklist based on pattern analysis. Arch Dermatol. 1998;134:1563–70.
3. Menzies SW, Ingvar C, Crotty KA, McCarthy WH. Frequency and morphologic characteristics of invasive melanomas lacking specific surface microscopic features. Arch Dermatol. 1996;132:1178–82.
4. Conway B. Neural mechanisms of color vision: double-opponent cells in the visual cortex. New York: Springer; 2002.
5. Conway BR. Spatial structure of cone inputs to color cells in alert macaque primary visual cortex (V-1). J Neurosci. 2001;21:2768–83.
6. Neitz J, Neitz M. The genetics of normal and defective color vision. Vision Res. 2011;51(7):633–51. https://doi.org/10.1016/j.visres.2010.12.002.
7. Foster DH. Color constancy. Vision Res. 2011;51:674–700.
8. Kitaoka A. A brief classification of colour illusions. Colour Des Creat. 2010;5:1–9.
9. Shive M, Ho D, Lai O, Mamalis A, Miller KM, Jagdeo J. The role of subtractive color mixing in the perception of blue nevi and veins-beyond the tyndall effect. JAMA Dermatol. 2016;152(10):1167–9. https://doi.org/10.1001/jamadermatol.2016.2201.
10. Fiete RD (2010) The imaging chain and applications. In: Modeling the imaging chain of digital cameras. Bellingham, WA: SPIE. p. 5–14.
11. Ribera Pibernat M, Harto Castaño AL, Bravo-Piris J. [The image in dermatology: medical photography]. Masson; 2000.
12. Taberner R. [Workshop in dermatologic photography]. https://es.slideshare.net/rtaberner/taller-de-fotografa-dermatolgica?next_slideshow=1. Accessed 28 Aug 2018.
13. Finnane A, Curiel-Lewandrowski C, Wimberley G, et al. Proposed technical guidelines for the acquisition of clinical images of skin-related conditions. JAMA Dermatol. 2017;153(5):453–7. https://doi.org/10.1001/jamadermatol.2016.6214.
14. Ohta N, Robertson A. CIE standard colorimetric system. In: Colorimetry: Fundamentals and Applications. Chichester: Wiley; 2005. p. 63–114.
15. Anderson RR, Parrish JA. The optics of human skin. J Invest Dermatol. 1981;77(1):13–9.
16. Badano A, Revie C, Casertano A, et al. Consistency and standardization of color in medical imaging: a consensus report. J Digit Imaging. 2014;28(1):41–52. https://doi.org/10.1007/s10278-014-9721-0.
17. ISO/IEC 10918-1:1994. Information technology—digital compression and coding of continuous-tone still images; 1994.
18. Jain AK. Fundamentals of digital image processing. Upper Saddle River, NJ: Prentice-Hall, Inc.; 1989.
19. https://www.datacolor.com/photography-design/product-overview/spyder5-family/
20. IEC 61966-2-1:1999. IEC Webstore. International Electrotechnical Commission. Retrieved 3 Mar 2017.
21. Piérard G. EEMCO guidance for the assessment of skin colour. J Eur Acad Dermatol Venereol. 1998;10:1–11.
22. Rodney A. Color management for photographers : hands on techniques for Photoshop users. Burlington, MA: Focal Press; 2005.
23. Vander Haeghen Y, Naeyaert JMAD, Lemahieu I, Philips W. An imaging system with calibrated color image acquisition for use in dermatology. IEEE Trans Med Imaging. 2000;19(7):722–30. https://doi.org/10.1109/42.875195.
24. Quintana J, Garcia R, Neumann L. A novel method for color correction in epiluminiscence microscopy. Comput Med Imaging Graph. 2011;35(7–8):646–52. https://doi.org/10.1016/j.compmedimag.2011.03.006.
25. Caffery LJ, Clunie D, Curiel-Lewandrowski C, Malvehy J, Soyer HP, Halpern AC. Transforming dermatologic imaging for the digital era: metadata and standards. J Digit Imaging. 2018;31(4):568–77. https://doi.org/10.1007/s10278-017-0045-8.
26. Quigley EA, Tokay BA, Jewell ST, Marchetti MA, Halpern AC. Technology and technique standards for camera-acquired digital dermatologic images: a systematic review. JAMA Dermatol. 2015;151(8):883–90. https://doi.org/10.1001/jamadermatol.2015.33.
27. Bajaj S, Marchetti MA, Navarrete-Dechent C, Dusza SW, Kose K, Marghoob AA. The role of color and morphologic characteristics in dermoscopic diagnosis. JAMA Dermatol. 2016;152:676–82.
28. Raina A, Hennessy R, Rains M, Allred J, Hirshburg JM, Diven DG, Markey MK. Objective measurement of erythema in psoriasis using digital color photography with color calibration. Ski Res Technol. 2016;22(3):375–80. https://doi.org/10.1111/srt.12276.
29. Radiology C. Standards for the provision of teleradiology within the United Kingdom RCR standards; 2010.
30. Munsell A. A pigment color system and notation. Am J Psychol. 1912;23(2):236–44. https://doi.org/10.2307/1412843.