Avoiding Complications and Pitfalls with Color in Dentistry

6

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Contents

6.1 Recognizing Color Blindness

The human eye works as a complex light capture system where cells, proteins, and their amino acids from the photoreceptors located at retina are major players, as described in Chap. 3. For the purpose of the present chapter, it is important to recall there are two types of photoreceptors: the cones, used for vision in daylight and for color vision, and the rods, used for vision in dim light. Thus, normal color vision in humans is trichromatic, that is, based on three classes of cones that are sensitive in the blue, green, and red regions of the visible spectrum, with maximum sensitive to light at about 440 nm, 540 nm, and 570 nm, respectively (Fig. 3.5). Each photoreceptor cell contains a single type of photopigment that is composed of a protein moiety (opsin) to which the chromophore 11-cis retinal is covalently bound. Thus, light absorbed by these photoreceptors is processed by neural circuits allowing perception of red, green, yellow, and blue colors individually or in many combinations. As previously mentioned (Chap. 1), such colors comprise the color axes (a^* = red-green axis and b^* = blue-yellow axis) of color space (Fig. 1.2).

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It has been observed that some individuals considered to have normal color vision present a slight variation in color perception, mainly in the red-green region of the spectrum, which is mostly explained by a large number of common variants of the red and green cone pigments generated by gene conversion (e.g., polymorphisms). However, there is a wide range of variation in defective color vision, with severity ranging from mild to severe color blindness. A color vision deficiency or impaired color vision is the decreased ability to see color or differences in color (color blindness). About 1% of males have no functional red cones (protanopes) or no functional green cones (deuteranopes), which are considered severe color blindness. These people have dichromatic color vision, which is based on the use of only two types of photoreceptors, blue plus green (protanopia—no red) or blue plus red (deuteranopia—no green). Males with mild color vision defects have, in addition to blue cones, either normal green plus anomalous green-like cones (protanomalous, ≈1%), or normal red plus anomalous red-like cones (deuteranomalous, ≈5%). These individuals have anomalous trichromatic color vision (Fig. 6.1). The anomalous pigments are red/green chimeras encoded by hybrid genes. The normal red and green pigment spectra overlap significantly but are well separated by wavelength of maximal absorption (λmax) of about 30 nm. The ratio of light absorbed by the red

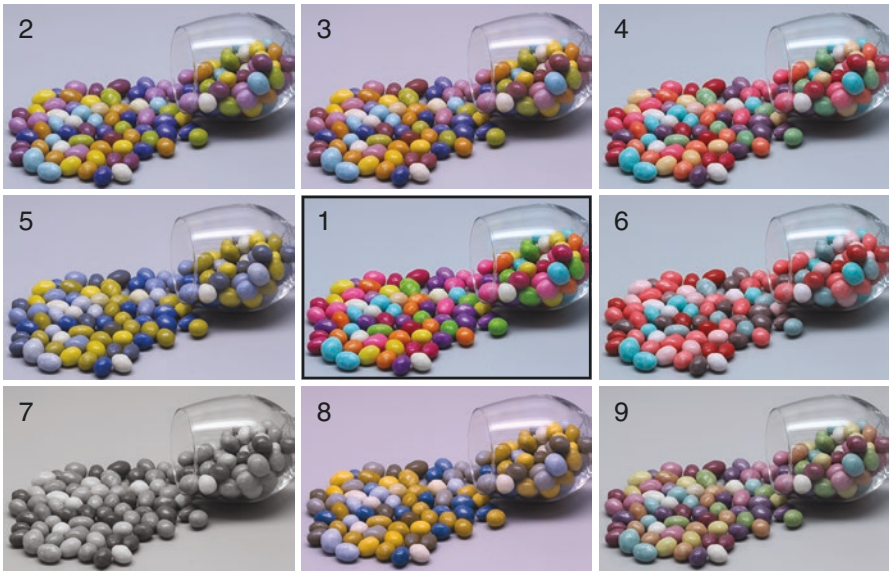

Fig. 6.1 Appearance of a natural scene to individuals with normal color vision (1) and simulated images (2–9) perceived by various types of color vision defective individuals. (2) Anomalous trichromacy, red-weak, protanomaly. (3) Anomalous trichromacy, green-weak, deuteranomaly. (4) Anomalous trichromacy, blue-weak, tritanomaly. (5) Dichromatic view, red-blind, protanopia. (6) Dichromatic view, blue-blind, tritanopia. (7) Monochromatic view, monochromacy, achromatopsia. (8) Dichromatic view, green-blind, deuteranopia. (9) Monochromatic view, blue-cone, monochromacy. Simulation of images was performed by software from Coblis—Color Blindness Simulator (freely available at http://www.color-blindness.com/coblis-color-blindness-simulator/)

and green cones at various wavelengths is the basis for color perception. Different colors (wavelengths of light) give different ratios of absorption. Protanomalous subjects have a normal green plus a green-like pigment with spectra that differ in λmax by 2–6 nm, and deuteranomalous subjects have a normal red plus a red-like pigment that differ in λmax by 2–9 nm. Therefore, these anomalous trichromats have diminished color discrimination capacity due to reduced ratios of light absorption from the red and green cones at various wavelengths. There are rare cases of individuals who have no functional blue cones (tritanopes, <1:10,000) because of mutations in the blue-pigment gene on chromosome 7. In addition, there is a blue cone monochromacy, which is a severe defective color vision based on only blue cones during daylight. Such individuals may have residual dichromatic color vision based on rods and blue cones during twilight. Figure 6.1 shows how an image is perceived by both normal (central image) and color-deficient individuals.

Whereas dichromats have severe color vision defects, anomalous trichromats vary in the degree of loss of color discrimination capacity. The severity of color vision defects among anomalous trichromats is strongly correlated with the difference in λmax between the red and red-like pigments of deutans (deuteranopia and deuteranomaly), and the green and green-like pigments of protans (protanopia and protanomaly). The smaller the λmax separation, the more severe is the defect. As only the first two genes of the array are expressed in the retina, severity of anomalous trichromacy is determined by difference in λmax (Δλmax) between the two pigments encoded by these two genes. It is worth noting that polymorphism (e.g., Ser180Ala) plays an important role in the spectral separation between the red-green hybrid and normal pigments and therefore in the severity of both protan and deutan color vision defects.

Therefore, genetics and molecular basis of variation in human color vision is a complex scenario. You have learnt that variation in red-green color vision exists among both normal and color-deficient individuals. Differences at amino acids involved in tuning the spectra of the red and green cone pigments account for the majority of this variation. One source of variation is the very common Ser180Ala polymorphism that accounts for two spectrally different red pigments and that plays an important role in variation in normal color vision as well as in determining the severity of defective color vision. This polymorphism most likely resulted from gene conversion by the green-pigment gene. Another source of variation is the existence of various types of red-green pigment chimeras with different spectral properties. The red and green-pigment genes are arranged in a head-to-tail tandem array on the X-chromosome with one red-pigment gene followed by one or more green-pigment genes. The high homology between these genes has predisposed the locus to relatively common unequal recombination events that give rise to red-green hybrid genes and to deletion of the green-pigment genes. Such events constitute the most common cause of red-green color vision defects. The severity of red-green color vision defects is inversely proportional to the difference between the wavelengths of maximal absorption of the photopigments encoded by the first two genes of the array. For more information on various aspects of the genetics of variation in normal and defective color vision refer to the further reading list at the end of this chapter.

In general, the frequency of red-green color vision defects among humans is around 7% for males and 0.5% for females. It seems such values are lower (4–5%) for Asian and African origin males. Therefore, reported frequencies of color vision defects vary not only with evaluated population (with main variables being gender, origin, and age) and method of testing, but also in the presence of systemic and eye fatigue or damage, medical conditions or chronic illnesses (e.g., Alzheimer's and Parkinson's diseases, macular degeneration, diabetes mellitus, glaucoma, and leukemia), and side effect of medication (e.g., some antibiotics and barbiturates). In addition, it has been considered head trauma, deficient diet, great emotional situations, and air pollution.

Nevertheless, studies have shown that the gender influences on the accuracy of visual shade matching are controversial. Some studies reported a better performance from males, others favored females, and many studies showed no evidence of gender influence on visual shade matching (Table 6.1). Such controversy is mostly because of the low number of color-deficient individuals in the population and lack of study power to detect any difference within the examined population.

As mentioned, the measuring method influences on the reported frequency of color vision defects, which is slightly higher when detected by anomaloscopy than values reported using Ishihara or Farnsworth tests. Yet, the later tests, along with the test for color discrimination competency, are the most used to evaluate color competency in Dentistry.

The *Ishihara Color Blindness test* evaluates the red-green color deficiencies, but can be also used to detect some types of acquired dyschromatopsia. It consists of colored plates, each of which contains a circle made of many different sized dots of slightly different colors, spread in a seemingly random manner. Within the dot pattern, differentiated only by color, the observer sees either a number or an abstract illustration. The original and complete test consists of 38 plates, but the existence of a deficiency is usually clear after several plates and, therefore, many studies used a short version of it, containing a 25-plate test (Fig. 6.2). The test can detect observers with protanomaly, protanopia, deuteranomaly, and deuteranopia (Fig. 6.1).

The *Farnsworth Munsell 100 Hue test* was originally developed by Dean Farnsworth, in the 1940s, and it has been used as a standard testing for color

Table 6.1 Studies reporting on the gender influence on the accuracy of visual shade matching

	Gender best performing on color perception		
Studies	Male	Female	No difference
Donahue et al. [1]	X		
Milagres et al. [2]	X		
Haddad et al. [3]		X	
Gasparik et al. [4]		X	
Pecho et al. [5]		X	
Imbery et al. [6]		X	
Barrett et al. [7]			X
Curd et al. [8]			X
Çapa et al. [9]			X
Poljak-Guberina et al. [10]			X
Silva et al. [11]			X

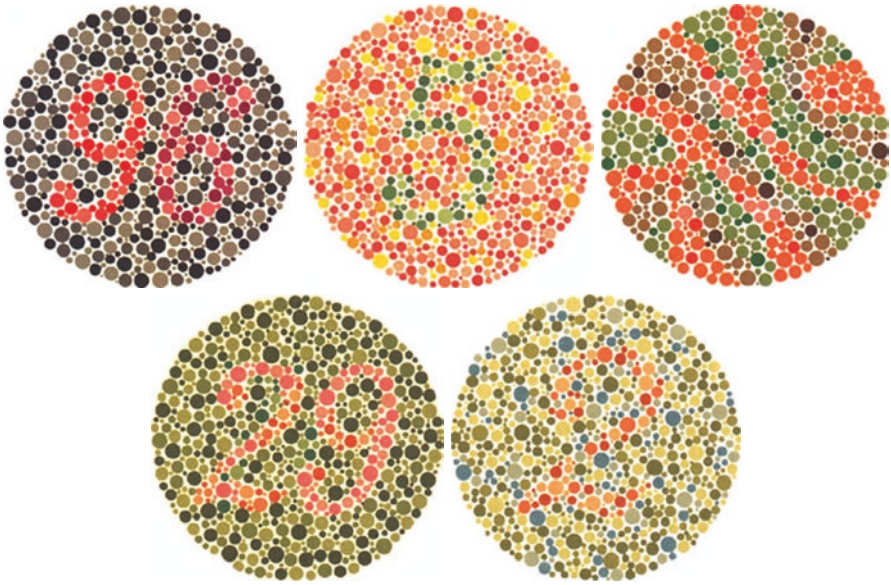

Fig. 6.2 Five plates from the Ishihara Color Blindness test. *Top left circle*—Normal vision observers see number 96, an observer with protanopia sees number 6, and an observer with deuteranopia sees number 9. *Top middle circle*—Normal vision observers see number 5, an observer with red-green blindness sees number 2. *Top right circle*—It is an abstract illustration. *Bottom left circle*—Normal vision observers see number 29, an observer with red-green blindness sees number 10. *Bottom right circle*—Normal vision observers see number 2, an observer with red-green blindness does not recognize any number

discrimination, which is the ability to discriminate between various hues of a given color. It tests the ability to isolate and arrange small differences in color, having constant value and chroma, covering all the visual hues from the Munsell color system. The aim of the test is to order the colored tiles (usually round pieces of about an inch in diameter) in the correct order. They are arranged in four rows based on color hue. They are organized in order to cover orange/magenta, yellow/green, blue/purple, and purple/magenta hues (Fig. 6.3). The test trays, where the tiles have to be organized, have a black background to isolate and accentuate color hues. Any misplacement can point to some sort of color vision deficiency (Fig. 6.4). It has been used to detect congenital and acquired dyschromatopsias. The test determines if the observer has superior (up to five-pair errors), average (from five-pair to eight-pair errors), or poor (above eight-pair errors) color discrimination.

You may find online, digital derivatives of the test, which is far more popular given its easy access for little or no licensing fee, and an apparent level of accuracy for most audiences. Taking the physical hue test under experimentally sound conditions (e.g., light booth or cabin under controlled illumination) is far more accurate, but the high price of the physical test kit is often prohibitive.

In any case, the test software makes it possible to record, organize, and analyze the testing data. This software is also able to indicate the color discrimination index

Fig. 6.3 The Farnsworth Munsell 100 Hue test

Fig. 6.4 Observer taking the Farnsworth Munsell 100 Hue test under controlled conditions (light or viewing booth)

and the type of color vision deficiency based on the number and type of errors for each test participant.

To qualify as an adequate observer for dental color research, potential observers should undergo either Ishihara test or Farnsworth Munsell 100 Hue test and the results should demonstrate, respectively, normal color vision or superior or average color discrimination.

In the *test for color discrimination competency in Dentistry*, the observers should match pairs of shade tabs from two shade guides. One set of tabs should have original markings on tab holders (e.g., A1, B1, 1M2, and 2M2) while the original markings of the other set of tabs should be covered with custom letters, numbers, or symbols (e.g., M, N, 1, 2, and 3) (Fig. 6.5). VITA Classical and VITA Lumin Vacuum (Fig. 3.6) are examples of appropriate shade guides for this test. Visual comparisons should be made under the D65 illuminant of a viewing booth (the overhead/room lights should be turned off), at the distance of 25–33 cm, using 0°/45° or 45°/0°optical geometry. Tabs should be removed from joint tab holders,

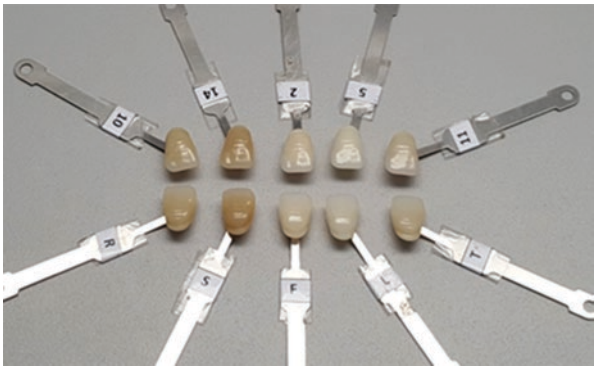

Fig. 6.5 Original markings from shade guide tabs were covered with custom letters and numbers for the color discrimination competency test

placed on the floor of the viewing booth and mixed. After a period of adaptation by observing the walls of the viewing booth, the observers should begin tab arrangement. At least 12 pairs of tabs should be used for this test and one point should be assigned for each correctly matched pair. The test can be repeated with at least 7-day interval between the tests, in which case the higher of the two scores will be counted (ISO/TR 28642:2016 standard).

Thus, as an alternative to Ishihara and Farnsworth Munsell Hue tests, and to be considered competent for color matching in dentistry, an observer should have correctly assigned at least 60%, 75%, and 85% of the sample pairs presented in the test for poor, average, and superior color discrimination competency, respectively. At least twenty observers with superior- and average-color discrimination competency should participate in evaluation of perceptibility and acceptability visual judgments in dentistry (ISO/TR 28642:2016 standard).

6.2 Instruction and Experience to Apply Color Science in Dentistry

Formal color education is rarely present on the curriculum of dental schools. Teaching and training on dental color are usually only part of a lecture on esthetic dentistry and, therefore, color sciences in Dentistry is mostly abbreviated to shade-matching exercises during clinical practices. Chapter 2 presented enough information for dental students and dentists to learn the basics of color science and optical properties and, therefore, correctly apply such knowledge to Dentistry. Considering the information from previous chapters, it is expected that you know how to use dental shade guides (Chap. 2), instrumental shade determination (Chap. 4), and adequate color communication (Chap. 5) in Dentistry. So, it is time to further discuss the influence of color science instruction and experience on color selection and esthetic results in Dentistry.

It has been stated that in shade matching, the eye is the finest null detector. Despite of it, we have learnt that the human eye works as a complex light capture system and that ordinary visual determination of teeth shade is subjective and inconsistent because many observer related variables (e.g., gender, color deficiency, experience, and eye fatigue) can influence on color perception. Furthermore, color

perception does not only vary between people, but it also fluctuates for the same individual over time.

In addition to such human variables, historically, shade determination and communication, and color perception and harmonization are the main color components involved in esthetic dentistry. They are strongly associated with the shade-matching process, which is the most popular clinical approach, but it involves minimal knowledge of color science. Therefore, esthetic excellence is largely an art with primarily subjective interpretation.

In general, in vitro shade matching or any investigation on color and optical properties is associated with homogeneously colored objects (Fig. 6.6). However, teeth vary in color and translucency, and their color perception is mostly related to their surface texture, shape, arch location, adjacent teeth color, and some dental disorders (Fig. 6.7). Consequently, teeth are more difficult to shade match than regular, plain objects (Figs. 6.6 and 6.7). Thus, the ability to either reproduce the exact shade of natural teeth or reach the desired shade using restorative dental materials is one of the most challenging goals in clinical dentistry. Such clinical procedures are

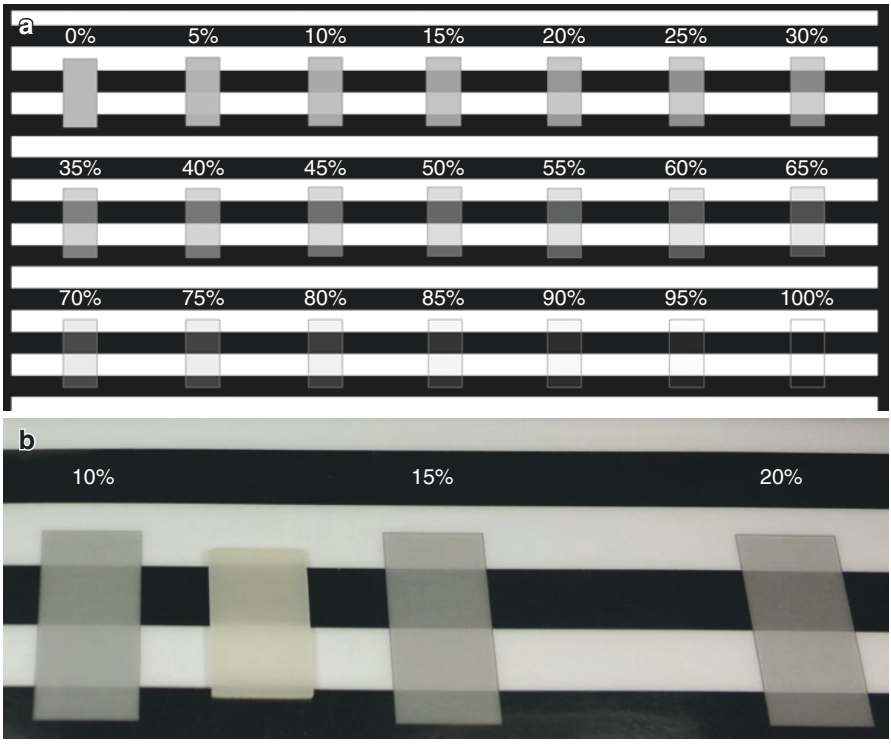

Fig. 6.6 (**a**) Translucency can be visually evaluated over black and white backgrounds. (**b**) The percentage of translucency of esthetic dental materials (e.g., resin-based composite) can be compared using a visual scale (**a**). Since constant thickness is crucial, in vitro dental color research usually uses flat, plain geometric specimens

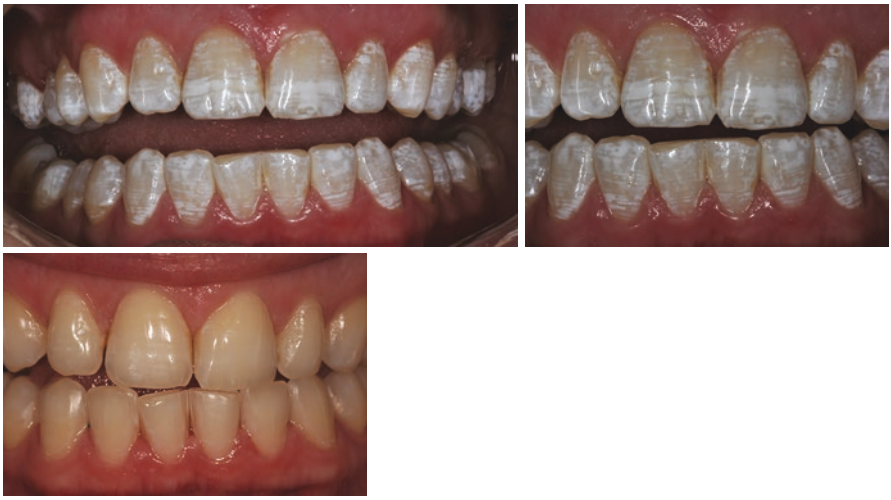

Fig. 6.7 What would be the color of these teeth (top two images) with no mild–moderate dental fluorosis (a disorder of tooth enamel caused by overexposure to fluoride during enamel formation, resulting in opaque white patches/stripes on the enamel)? Impossible to say before removing the superficial intrinsic tooth discoloration using micro-abrasion (bottom image). In addition to usual challenges of visual dental shade determination, the subjectivity of color perception is also confronted by some dental disorders, as shown in this Figure. Patient authorized Dr. A Della Bona to use intra-oral images

traditionally performed by visual shade matching using commercially available shade guides (e.g., Vita Classical and Vita 3D-Master—Chap. 3). Yet, it is important to bear in mind key concepts from Chaps. 1 and 3, such as: *translucency*, which is the gradient between transparent and opaque; *fluorescence* that is the absorption of short wavelength light with the spontaneous emission of longer wavelength light; and *opalescence* that makes a material appear one color with reflected light and another color with transmitted light.

Thus, to perform adequate shade selection for esthetic dentistry, we have to consider several information on color science applied to Dentistry, optical properties of dental tissues and materials, physiological and pathological conditions, position of the observer, surrounding conditions, and illumination. Then, one should know how to adequately report and communicate the selected shade. Theoretical and practical principles on these topics were provided in previous chapters, so we are now able to suggest a *clinical protocol to shade selection for esthetic dentistry* as follows:

1. Watch out for the surrounding environment. The surround is defined as the field outside the background. Clinically, the surround is considered the entire environment in which the stimuli are viewed. Therefore, the surround should be matte and neutral (light grey), removing any bright color from the working field. It is often necessary to cover patient's bright clothing with neutral color apron (bib) and remove colored lipstick and makeup.

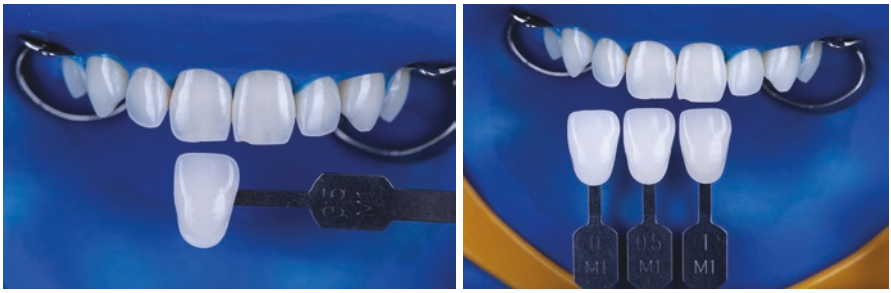

Fig. 6.8 Despite correct shade tab position related to target tooth, these images show a common clinical *mistake* on shade matching. Shade selection should be done at the beginning of the patient's visit, right after cleaning the teeth. Thus, avoiding enamel dehydration as shown in these images. Pictures taken by Matheus Basegio

2. Teeth should be cleaned. It is usually necessary to clean the target teeth using prophylaxis paste. Avoid enamel dehydration since it reduces translucency and increases in value, having a great chance of misleading the clinician on shade selection. So, cleaned and hydrated teeth (target object) are essential to shade selection. It is worth noting that shade selection should be made at the beginning of a patient's visit (Fig. 6.8).
3. Adequate shade guide. Use the most appropriate shade guide for the clinical procedure. In case of direct resin-based composite restorations, use the shade guide provided with the restorative system or make your own with the restorative material to be used. In case of indirect restorations, most of the ceramic systems follow either Vita Classical or Vita 3D-Master shade designation and, therefore, you should follow the one corresponding to the ceramic system to be used (Fig. 6.9).
4. Position and distance from target. Patient should be viewed at eye level and at arm's length, so the most sensitive part of the retina will be used. It often means a clinician–patient distance of, approximately, 30 cm.
5. Adequate illumination. Visual shade comparisons should be made under different lighting conditions. Initial shade may be taken under a color corrected fluorescent light and then confirmed in natural daylight. For the latter, you may take the patient to an operatory window, in case of adequate daylight.
6. Avoid eye fatigue. Visual shade comparisons should take less than 5 s to avoid eye accommodation and hue sensitivity. The observer may look at a gray wall or patient's bib between each shade evaluation.
7. Shade tab position (Fig. 6.10). Place shade tabs either above or below the tooth to be match, never place shade tab over or adjacent to the tooth to avoid binocular effect. Shade tab should be at same level and inclination as the target tooth. This rationale also applies to shade selection of tooth preparations.
8. Value first. Focus on value first, followed by chroma and then hue. Such method is followed by recent shade guides (e.g., Vita 3D-Master system—Chap. 3).

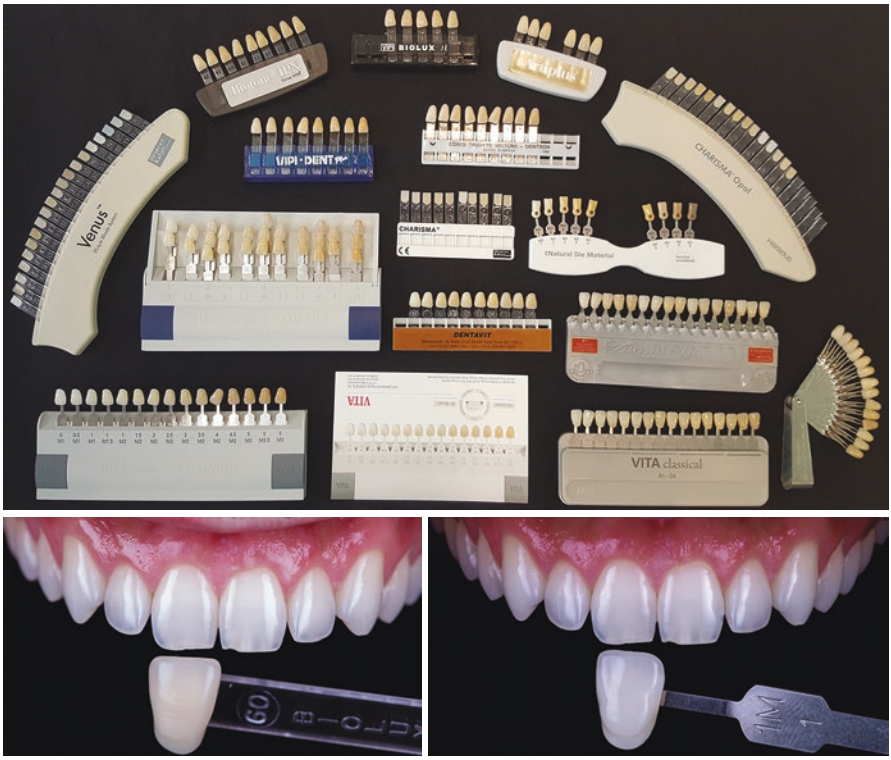

Fig. 6.9 It should be used the most appropriate shade guide for the clinical procedure. Most direct resin-based composite systems provide their own shade guide for enamel and dentine colors. So, do not use shade guide tabs from different resin-based composites (bottom left image). Ceramic systems usually follow either Vita Classical or Vita 3D-Master shade guides (bottom right image). Pictures taken by Matheus Basegio

9. Esthetic features. The target tooth should be divided into three regions (gingival, middle, and incisal or occlusal thirds) to focus on specific features. The gingival area often offers accurate determination of dentinal chroma. Enamel is thicker in the middle and incisal/occlusal thirds, varying from translucent to transparent. Natural and acquired features should be recorded for replication.
10. Adequate recording and communication. Advances in high-quality digital imaging technology along with digital photography and drawing (Chap. 5) have facilitated recording, simulation, and communication of all clinical features in esthetic dentistry, including color and optical properties. So, use whatever imaging system you are more familiar with, but do not forget to record and communicate any relevant information or feature, especially the shade tab designation (Fig. 6.11). It is worth noting that shade selection should not be done immediately after bleaching, patient should be recalled after few weeks for shade determination.

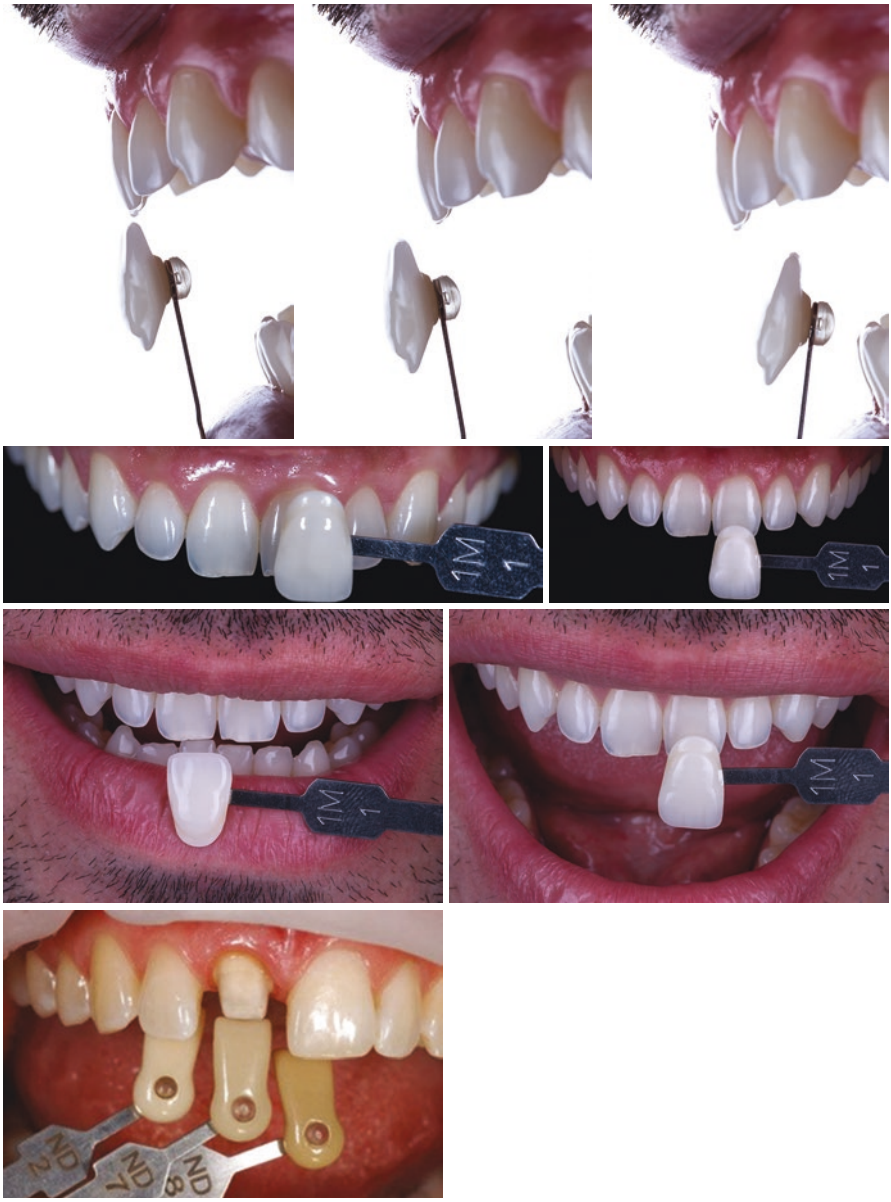

Fig. 6.10 Correct position of shade tab is shown at the top left image. The remaining images show common *mistakes* on positioning shade tabs for shade matching of a target tooth or preparation. Pictures taken by Matheus Basegio

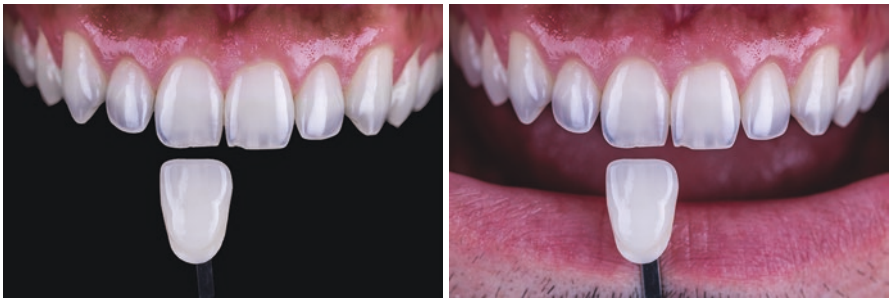

Fig. 6.11 Despite correct shade tab position related to target tooth, these images show a common *mistake* on shade communication: sending an image to dental laboratory with no shade tab designation. You may twist the tab handle so it fits in the image (as shown in the previous figure). Pictures taken by Matheus Basegio

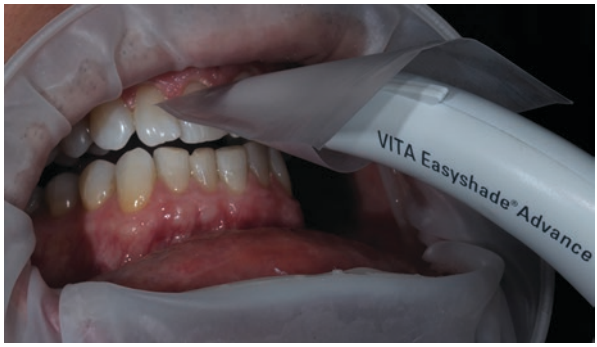

Fig. 6.12 Shade determination using a spectrophotometer (Vita Easyshade Advance)

Considering the innumerous aspects discussed in this textbook, color determination or dental shade matching is a subjective process. It is the subjectivity inherent in the visual shade-matching process that people try to overcome. Meaning, as the same color can be perceived differently among observers, it is feasible that instrumental shade identification may remove a certain subjectivity that arises from individual color perception. Thus, it has been reported that the main advantage of dental shade-matching instruments is their ability to reduce the imperfections and inconsistencies of visual shade matching. Yet, it has been demonstrated that instruments also have limitations, but color measuring instrumentation has facilitated and supported the clinician's shade selection to match the surrounding dentition and serve as an excellent tool to assist visual shade matching (Chap. 4).

11. Instrument shade selection assistance (Fig. 6.12). As mentioned, many factors can influence the perception of color and clinicians may take advantage of shade-matching technology and dental color measuring instruments

(e.g., spectrophotometers and colorimeters) to assist them on shade selection and communication (please refer to Chap. 4). It is recommended that instrumental color determination be always accompanied by experienced human visual perception.

To sum up, color is a psychophysical phenomenon that can be assessed by both visual and instrumental methods. Yet, additional elements including gloss, fluorescence, opalescence, and translucency affect esthetic dentistry and may influence the characterization of color appearance.

Therefore and despite the recent developments in industrial color difference evaluation, color matching still is largely dependent on visual perception. Although visual evaluation is highly subjective, shade-matching decisions exclusively based on instrumental color matching remain a desideratum far from resolution. With the incorporation of specific corrections on CIEDE2000 color difference formula (Chap. 1), the level of agreement between instrumental and visual color matching seemed to improve.

Similarly, recent developments on technology and materials have offered the chance to improve shade-matching skills in dentistry (Chap. 2). The ability to understand and distinguish color differences in visual shade matching is critical in clinical dentistry. Differences in shade perception due to observer variations can be minimized using additional observers and/or improving shade matching ability, mostly refer to experience. Thus, observers must be trained to optimize their color perception. Therefore, it is recommended that dental schools motivate students to study color sciences and the factors influencing shade matching. Such practicing skills can be learnt and trained clinically and online using the internet (Chap. 2).

Remember that one of the most important goals of any health care provider is restoring patient health, improving quality of life. Accurate shade selection that allows restorations to match the natural teeth positively influences the patient appearance and esthetic self-esteem, improving quality of life.

6.3 Management of Color Challenging Restorative Dentistry

The dental profession is experiencing great advances in materials and technology that positively influence the shade-matching process and color management in restorative dentistry. Yet, the overall shade replication process in indirect restorations, e.g., ceramic restorations, is more complicated than each part of the process suggests. In addition to all variables, mostly related to color science mentioned in previous chapters, there are further clinical and laboratory variables that can show single or cumulative effects on the final restoration. These additional variables include color of the substrate; composition, microstructure, thickness, and texture of the restoration; type of framework and veneering material, that is, the layering of

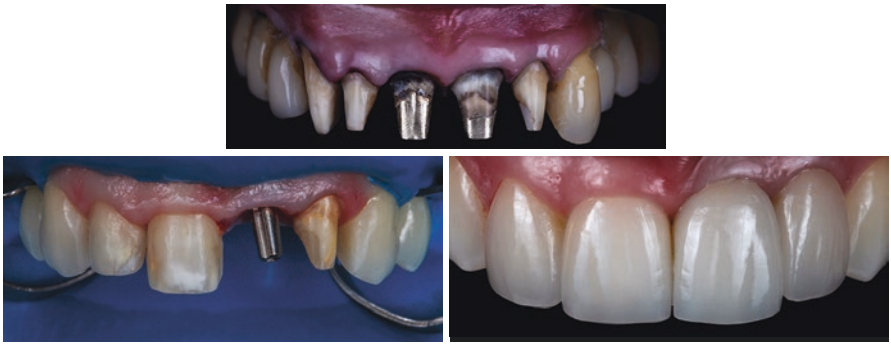

Fig. 6.13 Esthetic dentistry challenge to mask different colored substrates using ceramic restorations. Image on bottom right shows the esthetic ceramic treatment for the case shown in the bottom left image. Pictures taken by Matheus Basegio

the ceramic system; firing cycles and their parameters; technical skills of the ceramist; and color and opacity of luting agents.

In clinical situations requiring restoration of non-vital discolored teeth or metal abutment structures, dentists are confronted to choose materials to mask the underlying color producing an adequate esthetic restoration. That is one of the greatest challenges in esthetic dentistry. Additionally, the ceramic framework translucency was recognized as a key factor determining the optical characteristics of all-ceramic restorations. The challenge of masking discolored substrates using esthetic restorations is illustrated by two clinical cases (Figs. 6.13 and 6.14).

There are many CAD-CAM ceramic systems combining strength and esthetics to cover different clinical situations. Lithium disilicate-based glass-ceramic has generated considerable interest for restorative dentistry mostly because of adequate strength (350–450 MPa) and optical properties. Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) is still the strongest and toughness ceramic ever used in dentistry, but its limited translucency and the veneer porcelain chipping are major disadvantages for veneered Y-TZP systems. Future research will show if such problems are solved with the recent introduced monolithic zirconia restorations using highly translucent Y-TZP or with new techniques and materials to produce multilayered all-ceramic restorations (e.g., CAD-on system).

The clinical challenge of masking an undesired discolored substrate has been presented and vastly discussed. Different parameters have been used to evaluate the masking ability of restorative materials, such as contrast ratio (CR) and translucency parameter (TP). In addition, we have seen in previous chapters that CIELAB color space and its associated CIELAB (ΔE^*_{ab}) and CIEDE2000 (ΔE_{00}) total color difference formulas have been extensively used for color research in dentistry and, as a consequence, ΔE^*_{ab} or ΔE_{00} have also been used to evaluate the masking ability of restorative materials cemented on colored substrates (Table 6.2). Yet, the International Organization for Standardization (ISO/TR

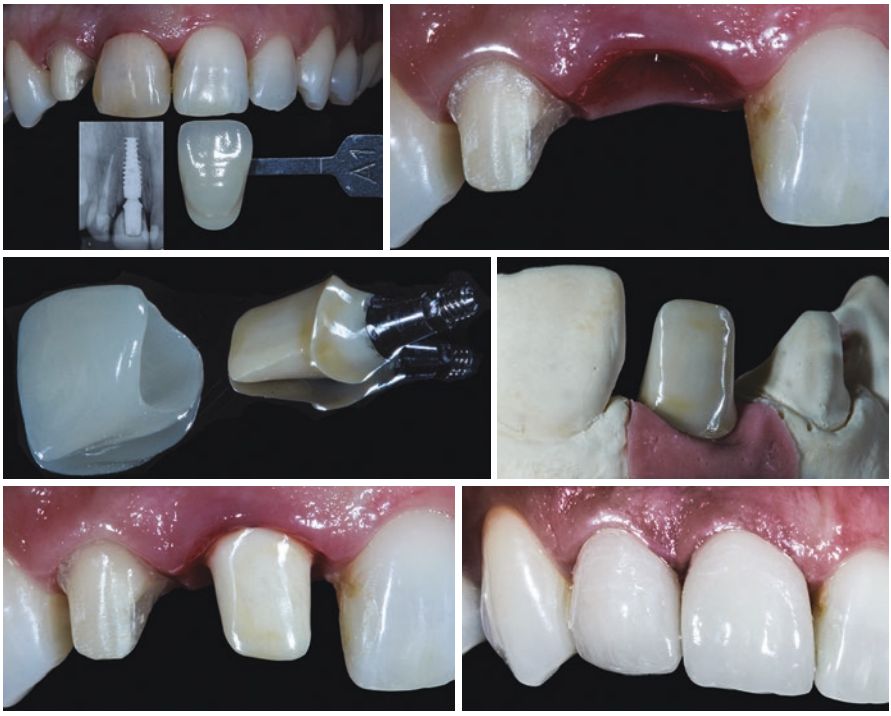

Fig. 6.14 Esthetic dentistry challenge to mask different colored substrates. Six months after extraction of the central incisor due to root fracture and implant placement. Temporary restoration on the implant was made using the crown from extracted tooth. The abutment infrastructure was customized on zirconia-based ceramic to mask the implant metal substrate. Crowns were fabricated using a glass-ceramic (IPS e.max CAD). Final case right after cementation of ceramic restorations. Pictures taken by Matheus Basegio

28642:2016) states that color differences should be assessed on the basis of 50:50% acceptability (AT: ΔE^*_{ab} = 2.66 and ΔE_{00} = 1.77) and 50:50% perceptibility (PT: ΔE^*_{ab} = 1.22 and ΔE_{00} = 0.81) thresholds. Thus, if the color difference between two specimens is at or below PT, it represents an excellent match; if the difference is between PT and AT, it represents an acceptable match; and if the difference is above AT, it represents an unacceptable match [12]. So, natural-looking restorations require adequate shade matching and blending optical properties from adjacent natural teeth that need to be accepted by the patient.

Table 6.2 Studies, in descending chronological order, and methods used to evaluate the masking ability in dentistry

Studies	Methods
Basegio et al. [12]	ΔE^*_{ab}, ΔE_{00} , TP and TP_{00}
Tabatabaian et al. [13]	ΔE^*_{ab}
Basso et al. [14]	ΔE_{00} and TP
Tabatabaian et al. [15]	ΔE^*_{ab}
Dede et al. [16]	ΔE_{00}
Tabatabaian et al. [17]	ΔE^*_{ab}
Oh and Kim [18]	ΔE^*_{ab} and TP
Boscato et al. [19]	ΔE^*_{ab} and TP
Begum et al. [20]	ΔE^*_{ab}
Farhan et al. [21]	ΔE^*_{ab}
Choi and Razzoog [22]	ΔE^*_{ab}
Shono and Al Nahedh [23]	ΔE^*_{ab}
Chaiyabutr et al. [24]	ΔE^*_{ab}
Takenaka et al. [25]	ΔE^*_{ab} and TP
Kim et al. [26]	ΔE^*_{ab} and TP
Chu et al. [27]	ΔE^*_{ab} and CR
Okamura et al. [28]	ΔE^*_{ab}
Chu et al. [29]	ΔE^*_{ab}

Further Readings

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