Shade Matching a Single Maxillary Central Incisor

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Accurately reproducing the unique characteristics of a single maxillary central incisor so that the artificial replacement is perceived as "natural" can be the biggest challenge in restorative dentistry. This challenge comes at several levels. First, the practitioner needs to have an understanding of what factors go into achieving a good match as well as some basic knowledge of the nomenclature of light science in order to communicate what is seen. Second, the practitioner is responsible for creating a protocol to accurately assess what is happening when light hits the surface of the tooth to create its appearance. There are ways to enhance what we see visually or photographically in the mouth by lessening metamerism, afterimages, and other visual distortions.

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Third, the practitioner needs to develop written, graphic, and photographic communication devices that are more comprehensive and less confusing. For example, there is no common dental standard for communicating the degree of translucency, hypocalcification of enamel, or varying degrees of surface luster. If we had to describe in great detail the teeth shown in Fig 1 without photography, how many words would it take to deliver a nonconfusing synopsis? And last, laboratory staff needs to develop their skills along with the practitioner partner because all of the levels of communication conveyed to the lab must also be recognized and understood in the photographs.

It is important to realize that matching the hue and chroma is fifth or sixth in importance on the list of things to match when constructing a prosthetic replacement.[1] A person would have to be fairly close to detect subtle differences in hue; yet disparities in surface morphology, value, and opacity can be seen from 4 or 5 feet away or more. Disparate tooth silhouettes or perimeter shapes of the teeth can be seen from even 10 feet away. The order of importance while matching a single maxil-

Fig 1 How easy would it be to describe these teeth in written form?

lary central is *(1)* silhouette or perimeter shape, *(2)* surface morphology and texture, *(3)* value, *(4)* translucency or opacity, *(5)* chroma, and *(6)* hue.

SHAPE, MORPHOLOGY, AND TEXTURE

The appearance of teeth is mostly determined by how light interacts with its curved and varied surface. The perimeter shape and the morphology of the buccal surface have the greatest affect on the appearance of teeth because they determine how the majority of light is reflected. An observer only sees an object when light comes from that object. Surfaces that are smooth and perpendicular to us send more light back to us (Fig 2). Reflective surfaces of the tooth will not return significant light to our eyes if they are not perpendicular to our eyes, even if the tooth surfaces are highly polished. Figure 3 illustrates this concept with sand that is uniform in color. The sand looks very different depending on its contour and angle of illumination.

The textures of a maxillary central incisor can be divided into three subcategories: vertical, horizontal, and localized. Vertical textures tend to be manifestations of the three developmental lobes. Horizontal textures are initially created by the placement of enamel layer upon layer. The end of each layer leaves a line on the enamel surface called *the striae of Retzius*.[2] These striae run roughly parallel to each other and are called *perichymata*. As the years go by, the surface of the tooth wears and the striae eventually disappear. Different sections of the tooth calcify with different levels of mineralization and hardness. In time these dissimilarly hardened areas can wear unevenly, forming much larger and more widely spaced horizontal undulations. The localized group of surface textures is a catchall for characterizations such as “orange peel,” stippling, cracks, craze lines, chips, developmental defects, etc.

Reflection from a smooth surface results in the production of a clear, well-defined image. This is called *specular reflection*. A specular reflection returns a high percentage of direct, nondiffused light and, if strongly illuminated, will be brighter and stand out. Most teeth have irregular surfaces with convexities and concavities. The convexities (Fig 4) tend to wear and become smooth with specular reflective characteristics. Concavities tend to collect light by reflecting inward and are often unpolished, thus diffusing the light and returning less light to the viewer’s eyes. The visual impact of a tooth comes from the specular highlights that reflect off the heights of contour and give the tooth its visual shape and perceived length and width dimensions.[3]

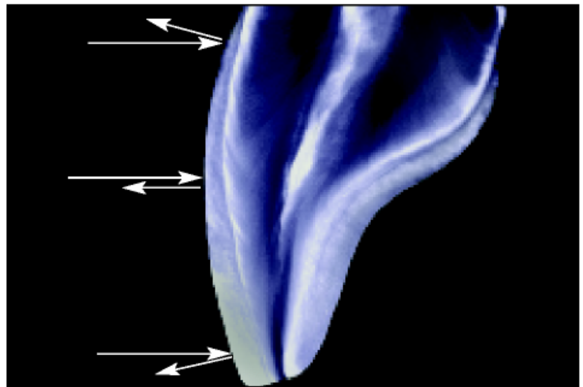
Smoothing the texture of the buccal surface makes teeth appear lighter and brighter and therefore gives them a significant determinate of value. The more reflective the surface, the more wavelengths return to the observer’s eyes, and the additive combination of more wavelengths yields whiter light (hue, chroma, value, and opacity all change). If we were to smooth out the wind-rippled sand in Fig 3, it would appear brighter. Brighter objects appear closer to the viewer. This is why a restoration that is too light appears to “jump out at” the viewer. Lowering the value makes objects appear farther away.

Silhouette and surface morphology are best documented with photography. Photographic protocols are described later in this article. Value is the next most important parameter of color matching.

Fig 2 You only see an object when light comes from that object. A high percentage of light that hits a surface at a 90-degree angle will return to the viewer, while light that hits a surface at an oblique angle will be deflected away from the viewer.

Fig 3 Appearance varies depending on surface contour and the angle of illumination.

Fig 4 Convexities tend to polish over time and become reflective and bright. Concavities tend to be darker with rougher and non-perpendicular surfaces deflecting and dispersing light.



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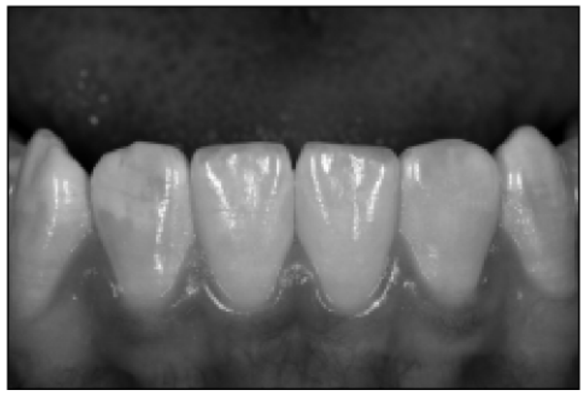

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VALUE

Value, or brightness, is the sum total of light that returns from the target tooth (contralateral maxillary central incisor) to the eyes. The brightness of teeth is mainly determined by the saturation or intensity (chroma) of hue and the surface reflectivity as discussed above but is also appreciably affected by the optical characteristics common to translucent bodies. These optical characteristics, in order of importance, are opacity, opalescence, fluorescence, and optical density.

Human teeth are characterized by varying degrees of opacity. Translucency and opacity can be defined as the measurement of the gradient between transparent and opaque. Value is affected by the opacity of the various layers of the tooth. As the opacity increases, more light is scattered instead of being transilluminated. Reducing the surface luster of a piece of clear window glass by wet sanding or etching produces a frosty-white look. As light hits the surface of the etched glass, it scatters or bends irregularly. This scattering of the light at the surface causes an increase in opacity (Figs 5 and 6). The light does not travel through and away from the surface but rather is reflected. As the glass becomes less translucent, the value increases. The net effect is that more light returns to the viewer as the luster diminishes.

Polishing the rough glaze off a porcelain restoration is a subtle way to lower value by making the porcelain clearer and more translucent.[5] Super-polished surfaces can appear bright because of the crisp specular reflection, but they also have more translucency because the light is not scattered or bent at the surface. It is important to note that surface texture, and not luster, determines specular reflection. With the window glass

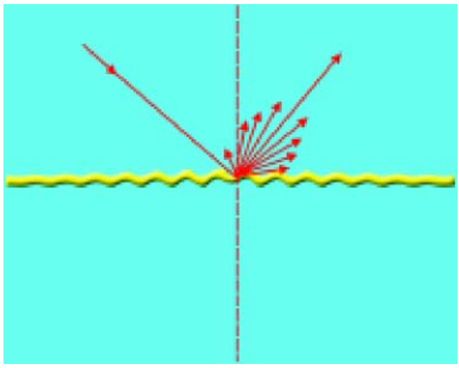

Fig 5 A roughened surface diffuses light.[4]

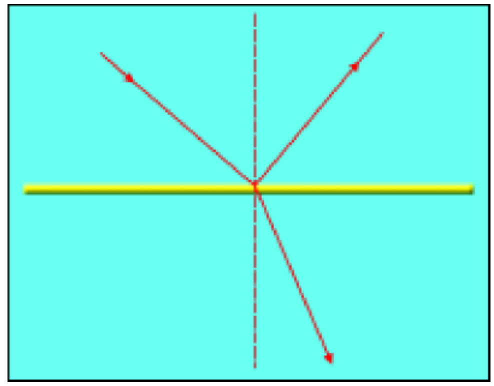

Fig 6 A smooth, polished surface produces a well-defined image and can be more translucent.[4]

example, although the surface has been roughened, the glass remains flat and has low texture, so it will remain a specular reflector.

Opalescence can be described as a phenomenon where a material appears to be one color when light is reflected from it and appears to be another color when light is transmitted through it.[6] A natural opal is an aqueous disilicate that breaks transilluminated light down into its component spectrum by refraction. Opals act like prisms and refract (bend) different wavelengths to varying degrees. The shorter wavelengths (blues and purples) bend more and have a higher critical angle needed to escape the optically dense enamel than the longer wavelengths (reds and yellows). The hydroxyapatite crystals of enamel also act as prisms. When illuminated, enamel will transilluminate the reds and scatter the blues within its body. This is why enamel not backed by red-yellow reflecting dentin, such as at the incisal edge or interproximally, will appear bluish even though it is intrinsically colorless.[7–9] The opalescent effects of enamel brighten the tooth and give it optical depth and vitality.[10] The easiest way to evaluate enamel thickness is to look for the opalescent blue areas. Documentation of the translucent enamel is best done photographically since dentistry lacks the words to describe levels of opacity.

Fluorescence by definition is the absorption of light by a material and the spontaneous emission of light with a longer wavelength.[11] Fluorescence in a natural tooth primarily occurs in the dentin because of the higher amount of organic material present.[2,7,8,12] The more invisible ultraviolet (UV) light the dentin absorbs, the more it fluoresces, therefore increasing the value.[7] We live in a world of UV light. UV light can have a dramatic effect on the brightness of teeth and restorations. The dental practitioner cannot measure fluorescence easily, but the porcelains used in the restoration should have fluorescent qualities or else the value will be too low in sunlight or other high UV situations.

When light enters enamel, it gets bounced around the enamel. If one side of a tooth is illuminated with a curing light, the entire crown is lighted. Similar to a fiber-optic cable, enamel is an optically dense material bordered by air and dentin, both of which have significantly lower optical densities. Normally, increasing opacity or reflectivity increases value. By increasing the optical density of dental ceramics, the fiber-optic properties of natural enamel can be replicated, and the prosthetic crown can be bright and translucent at the same time. It is with the translucent enamel layer that the ceramist achieves color depth and the illusion of a vital natural tooth. Measurement of optical density is difficult and not necessary, but porcelains that have higher optical densities tend to be more lifelike.

CHROMA AND HUE

Every opaque object in your sight is receiving light or is receiving the three primary color ranges of red, green, and blue-violet in some ratio. Some of these objects reflect all of the light they receive and others absorb it almost completely.[7] Most "opaque" objects absorb part of the light and reflect the rest. The dominant wavelength(s) reflected back to your eye is the perceived color of the object. White objects reflect almost all visible light rays. Black objects absorb most of the light so nothing is reflected back to your eyes.

Hue is the quality that distinguishes one family of colors from another. Hue is specified as the dominant range of wavelengths in the visible spectrum that yields the perceived color. Chroma is the saturation, intensity, or strength of the hue.

SHADE ASSESSMENT SYSTEMS

Shade tabs from any vendor are helpful. Ideally practitioners should have the same shade guide the laboratory uses, but if not, the tab can be shared while the restoration is being completed.] The Vita classic shade guide (Vita Zahnfabrik, Bad Säckingen, Germany), at this time, is used by about 90% of practitioners. This guide unfortunately represents a minority of the natural teeth and unnaturally brightened teeth to be matched. It is hoped that a nonproprietary, universal, full-spectrum guide will be available in the not-too-distant future that the dental material manufacturing industry will adopt. Better shade tab systems that cover more of the hue and value spec- trums, such as the Vitapan shade guide, are currently on the market; however, Vita- pan is tied to a proprietary porcelain system.

The current mechanical shade-assessing systems based on colorimeters, spectrophotometers, or camera sensors (charge-coupled device or CMOS) will not rival the results achieved when the practitioner/technician team utilize well-drawn shade maps and quality multi-image photography.[13]

MEASURING LOW-LIGHT VALUE

Value is best evaluated in low or subdued light. When the Vita classic shade guide is arranged by order of value (as suggested by the manufacturer) and evaluated in good light, the order might be considered suspect. Some of the darker-appearing tabs seem to be in the middle. If viewed in subdued light (the amount of light present during an ominous thunderstorm with dark clouds), the order seems perfect. The discrepancy occurs because of color confusion. In more light the color- perceiving cones in our eyes are stimulated and the color in the tabs becomes more evident. The colors confuse the observer's ability to assign value intensities. In lower light, the cones are not stimulated and only the rods are activated. The rods in our eyes are sensitive to lightness and darkness, or grayscale. Rods, which are used in night vision, are very sensitive even with small amounts of light. The cones are activated only with higher light levels. (Consider that, except for colored lights, we do not see colors at night when driving.) In summary, ambient light levels should be low enough so that colors are not that obvious and only the rods in your eyes are used to assess the brightness of the target tooth. Some authors have suggested squinting as a way to assess value.[14,15] The practitioner should instruct the laboratory to confirm in low light the overall value of the final restoration.

Low-light value should be the first parameter evaluated in the restorative procedure. By assessing low-light value first, the pupils have not been closed down by the glare of the bright dental unit light.[16] Also, the tooth has not become dehydrated. Dehydration increases opacity of the enamel. Light no longer can go from hydroxyapatite crystal to crystal. Intraoperative dehydration causes significant changes in value, translucency, chroma, and hue. Less translucency causes more reflection, so the tooth is brighter.[12] Chroma, being inversely related to value, is reduced, and the hue becomes more the color of the light source, which is assumed to be white. Once the low-light value is determined, hue and chroma tabs can be selected.

SELECTING SHADE TABS

Create a neutral-colored environment. Complementary-color afterimages of any bright color will occur in milliseconds. The ideal background when assessing color is neutral gray.[17,18] Neutral gray has no complementary color and is restful to the cones. A neutral gray environment is more critical with aged teeth that have a glossy surface that reflects the shade of any color placed in close proximity (Aiba N, personal communication, 2001).[18–20] The color of the walls in the operatory and laboratory can alter color perception and should be subdued. In a blue room more orange is seen than is actually present because the complement of blue is orange. A gray bib can be used to cover the patient's clothes,[21] and lipstick should be removed or covered. The amount of red tissue seen in the background can be limited by cropping it out with intraoral gray backgrounds (Pensler Shields, #50009211, Kulzer. These disposable cardboard backgrounds can be shaped easily to match the arch form. If the background card is positioned too far behind the teeth and out of focal distance, the gray will darken to black, which increases glare.[7, 22]

The most important parameter of selecting hue is the lighting condition. Due to the variability of daylight, blinds should be used. The practitioner and the laboratory should have color corrected artificial lighting that 1) approaches 5500 degrees K, 2) has a color rendering index of greater or equal to 93, and 3) proper luminosity. Viewing teeth under diffuse illumination will minimize the distortion of reflected light. Reflection from the specular surfaces of a tooth reveals more of the color of the illuminating light than the color of the tooth.[23] The average recommended luminosity for dental shade matching is 150 foot-candles.[15,19,24–27] To have light of this intensity in the operatory at the level of the dental chair, 8 to 10 4-ft fluorescent bulbs would be needed in a 10 x 10-ft room with 8-foot ceilings.[19,26] The diffusion panels covering fluorescent bulbs are important because they can screen out wavelengths. As they age, the panels change what wavelengths they absorb. The best diffusers, preferably the "egg- crate" type, are those that do not filter out any wavelengths of the spectrum. Using 10 color-corrected bulbs on the ceiling will yield more light in the operatory than would be considered comfortable. Portable high-quality light units, such as the Vident light, are ideal.

First impressions are the best, because of the effects of eye fatigue. To prevent hue accommodation, practitioners should not stare at the teeth for more than 5 seconds.[15] Miller has suggested using a Vita classic shade guide arranged by hue with the A and B hues at opposite ends and C and D in the middle. C and D have hues in between A and B[28] on the linear rainbow (chroma and value are manipulated to yield different looks). When choosing the hue family, a clinician can use the A4 and B4 or A2 and B2 tabs, which facilitate the process of elimination by using tabs with the greatest hue spreads.[15] The chroma is very low for shades A1 and B1. It can be difficult to distinguish the proper hue family using these tabs. When choosing the hue with a shade tab, the practitioner should look to the midbuccal area of the tooth. Differences between the shade tab and the natural colors of the tooth increase near the root. Compared to the Vita classic shade guide, natural teeth exhibit increased redness and lower translucency at the cervical aspect.[20,29] If in doubt about the hue family, the A family can be chosen,[30] since perhaps as many as 80% of natural teeth are a closer match to this hue family (Miller L, personal communication, 2001). Most natural teeth have more red than is in the B family. Another guideline for shade matching is to hold the incisal edge of the shade tab to the incisal edges of the teeth. This position effectively isolates the shade tabs from the teeth so they do not reflect onto each other (Aiba N, personal communication, 2001)[20]; it also reduces afterimages.

Most humans experience eye dominance, and one eye will preferentially perceive shade.[16] It is wise to hold the shade guide on both sides of the tooth at each vector (Aiba N, personal communication, 2001). In addition, difficulties can arise when the tooth being examined differs considerably in size from the specimen on the shade guide. A variation in color perception can occur with the relatively larger area appearing brighter and more vivid than the smaller area.[31]

SHADE MAPPING

In dental ceramics, clinicians and technicians try to imitate the appearance of the tooth as a sum of all its visual dimensions. In addition to providing excellent photographic images for the technician, it is extremely valuable to provide a written graphic with an interpretation of these dimensions in the drawing. If no shade tab matches what is seen, then a tab can be customized by applying surface stains. Caution must be used with this technique because the lab is encouraged to duplicate this surface staining, which will increase metamerism in the final restoration.[32,33]

All that is seen should be shade-mapped in full- page, three-dimensional drawings or on printed photographs of the target tooth and other proximal teeth. Several views (eg, 90-degree straight buccal, 135-degree angle from the buccal-incisal aspect, and straight incisal/occlusal) can be used. The labial face of the crown is then divided into zones. The low-light value from gingival to incisal should be noted, and the base hues should be mapped, along with the chroma stops in the various areas of the buccal surface. A chroma stop is an arbitrary measurement of hue saturation and is designated by the number of the Vita classic shade guide. Do not hesitate to alter these chroma-stop designations. For example, it is acceptable to note an area to be A2.5 or A3.75 even though there are no tabs that have these chroma intensities.

The surface anatomy must be described. The preoperative models will help in duplicating the contours. Although the luster and texture can be better determined photographically, the clinician should describe it on the prescription form and include the age of the patient. Surface texture and luster can be described as heavy, moderate, or light, and different combinations of surface characteristics can be given. Because these surface features determine the character of light reflection and affect the amount of light that enters the tooth, the surface morphology of a crown should be designed to simulate the light transmission and reflectance pattern of adjacent teeth.[4,5,29,34–38]

When the practitioner is mapping the translucency of the target tooth, he or she looks for the opalescent blue areas. They are more visible with the use of a black background, which limits the reds reflecting from the back of the mouth recombining with the blues to yield white light again.[39,40] When drawing proximal translucence, the clinician should ask the patient to turn from right to left, which allows a better analysis. This reevaluation at different angles is called vectoring.[16,36,41,42]

The practitioner and technician should build a collection of shade guides and tabs that can be shared between the team. Some proprietary guides have tabs that represent different levels of enamel opacity, frost, occlusal staining, etc.

PHOTOGRAPHIC DOCUMENTATION PROTOCOLS

Developing expert photographic skills is worthwhile because better images yield more information. The practitioner is responsible for creating an environment and protocol to assess what is happening when light hits the surface of the tooth to create the appearance of the tooth. There are ways to increase what is seen photographically in the mouth,[40,43] and some fairly simple choreographed images serve to communicate the more important parameters for matching. Communicating with photography will always be better than with written or verbal descriptions. Almost all quality levels of images are better than nothing. That alone should encourage more photographic documentation.

Shape, surface morphology, translucency, chroma, and hue can all be documented well

Fig 7 Surface morphology is best documented by increasing flash reflections. Hold camera perpendicular to three buccal planes of tooth.

Fig 8 Translucency is best documented when limiting the flash reflections by angling the camera lens greater than or equal to 30 degrees from perpendicular to the buccal surface.

using three choreographed photographs: one each for silhouette and surface morphology, translucency, and hue and chroma.

Silhouette and Surface Morphology

When the lens and flash are positioned over the surface of the tooth, the light will reflect off the perpendicular surfaces back to the camera, as off a mirror. All surfaces not perpendicular will reflect the light away from the camera, highlighting the texture variations (Fig 7).

The following guidelines will help to obtain a photograph that best represents the tooth silhouette and surface morphology:

- Use a black background. (This is preferred but not mandatory.)
- Orient the camera lens perpendicular to the surface being evaluated.
- Dry and clean the surface of the tooth.
- Vector for gingival, midbuccal, and incisal thirds.
- Use a dual-point or circumferential flash to best capture surface morphology. These types of flash mechanism maximize the reflections.

Translucency

Camera flash reflections are very helpful when evaluating textures. However, these reflections obscure the view below the surface of the tooth. Flash reflections should be minimized in the photograph when evaluating translucency. The target tooth can be wetted for evaluation of translucency, hue, and chroma to limit the influence of surface morphology. Reflections can be limited by angling the lens (more than 30 degrees) away from perpendicular to the target tooth surface and taking the photograph from above or below (Fig 8). More angulation may be necessary with a ring flash since ring flashes tend to surround the exposure field and yield more reflections.

A few steps will enhance translucency in a photograph:

- Clean the teeth.
- Use a black background.
- Close down the aperture to allow discernment of layers and depth.
- Set the flash on manual (turn off through-thelens [TTL] flash) and slightly underexpose by incrementally adjusting the F-stop. Closing down the F-stop increases the depth of field and will improve your ability to see the layers within the tooth. This will decrease the influence of surface reflection but not decrease your ability to see the opalescence.
- Angle the lens at least 30 degrees from perpendicular so reflections do not return to camera.

Fig 9 Chroma and hue can be communicated when three shade tabs (three chroma stops of similar hue) are placed edge to edge with the reference tooth and a reflective gray card is set in the background.

Chroma and Hue

Visual distortions dramatically affect our ability to render color.[7] The two main distortions in dental circumstances are the spreading effect and the negative afterimage. Simply stated, the spreading effect occurs when two dissimilarly colored objects are placed next to each other. Because our eyes do not stare fixedly at an object but rather continually roam the visual field, the color of one object is mixed with that of another object, and within seconds the objects appear more alike. If some distance is placed between the tooth and the midbuccal part of the shade guide, a better assessment can be made. Some clinicians advocate grinding off the incisal edge of the Vita classic shade tabs, but the incisal edges of the tabs do help provide that little visual separation, which lessens the spreading effect[7, 22,44] (Aiba N, personal communication, 2001). Orient the shade tabs so that the incisal edge of the tab approximates the incisal edge of the tooth (Fig 9).

Contrast is caused by a difference between the brightness or color of an object and its immediate background. Object forms with high contrast are easier to detect than objects with low contrast. While some contrast is helpful to our visual system, excessive contrast causes glare. An extremely bright object against a dark background causes discomfort and can interfere with color perception.[7,22] This interference is generically called *glare*. This glare reduces our ability to perceive visual information. With dental photography, the use of a black background increases impact, but it will cause glare. An increase in glare is counterproductive when matching hue and chroma, and it will mask shade mismatches.

Negative afterimages are caused by fatigue of the cones in our eyes. Afterimages are often seen in the form of complimentary colors. Background reds in the mouth create the perception of more blue than is actually present. An achromatic background is quite valuable in hue assessment. The 18% reflective gray card is the photographic industry standard achromatic background. A gray card creates less glare and fewer afterimages.

Chroma and hue can be effectively recorded by following these recommendations:

- Clean the tooth surface. Saliva can be left on the surface, as water tends to flatten the surface and lessens distracting flash reflections caused by surface textures.Use an 18% reflective gray card background.
- Take the photographs at least 30 degrees from perpendicular to the surface to prevent reflections that will obscure proper evaluation.
- Arrange three shade tabs incisal edge to incisal edge. Tabs should be parallel and equidistant to the teeth from the lens. The center tab is considered an ideal match, while the other tabs represent one chroma stop up or down.
- Create slight underexposure by using manual flash settings rather than using TTL flash and adjusting the compensation settings. This will make chroma evaluation easier.
- Using the viewfinder, crop as much red tissue out of the image as is possible without cropping any of the target tooth

Bracketing in Manual Mode

Varying the film/sensor exposure can be accomplished several ways and is called *bracketing*. One type of bracketing is the incremental adjustment of the lens aperture by fractions of an F-stop while multiple exposures are being taken. When the aperture, or lens opening, is closed down, less light will reach the film or digital sensors. Bracketing F-stops is beneficial in documentation photography because often different things are seen at different settings. Closing down the F-stop will decrease the influence of surface reflections but not decrease the ability to see the opalescence. It also increases the depth of field. Closing down the F-stop will increase the ability to see the layers within the tooth, which is helpful for determining translucency, hue, and chroma.[45] The camera has to be set to manual with a constant shutter speed and flash. The TTL flash setting cannot be used with this technique. All exposures can be sent to the laboratory, but the slightly underexposed images deliver more information.

SUMMARY

To produce a lifelike restoration, it is important for the clinician and technician to develop their skills at describing the features of a tooth. A sequential protocol for selecting value and shade tabs, shade mapping, and then photographing for shape and surface morphology, translucency, and finally chroma and hue has been described. This protocol allows the clinician to capture detailed and accurate information about the appearance of the tooth, which will aid the dental technician in creating a faithful reproduction. The steps described in this article should be followed before any restorative procedures are performed and even before the dental unit light is turned on. The laboratory needs to develop itself along with the practitioner because all the levels of communication conveyed to the lab must be recognized and understood by the technician.

REFERENCES

1. Fondriest JF. Shade matching: The science and the strategies. Int J Periodontics Restorative Dent 2003;23:466–479.
2. Orban BJ. Oral Histology and Embryology, ed 6. St Louis: Mosby, 1976.
3. Rufenacht C. Fundamentals of Esthetics. Chicago: Quintessence, 1992.
4. Ubassy G. Shape and Color: The Key to Successful Ceramic Restorations. Chicago: Quintessence, 1993:197–204.
5. Ancowitz S, Torres T, Rostami H. Texturing and polishing: The final attempt at value control. Dent Clin North Am 1 998;42:607–61 2.
6. SundarV, Amber PL. Opals in nature. J Dent Technol 1 999;1 6(8):1 5–17.
7. Overheim D. Light and Color. John Wiley and Sons, 1982.
8. Winter R. Visualizing the natural dentition. J Esthet Dent 1993;5:102–1 17.
9. ten Bosch JJ, Coops JC. Tooth color and reflectance as related to light scattering and enamel hardness. J Dent Res 1 995;74(1):374–380.
10. Garber D, Adar P, Goldstein RE, Salama H. The quest for the all-ceramic restoration. Quintessence Dent Technol 2000;23:27–36.
11. McLaren E. Luminescent veneers. J Esthet Dent 1 997;9:3–1 2.
12. Cornell D, Winter R. Manipulating light with the refractive index of an all-ceramic material. Pract Periodontics Aesthet Dent 1999;11:913–917.

13. Fondriest JF. The use of colorimeters in shade communication. Journal of Cosmetic Dentistry 2004; 20(3):104-108
14. Glick KL. Color management of cosmetic restorations. Curr Opin Cosmet Dent 1995:36–40.
15. Miller LL. Esthetic dentistry development program. J Esthet Dent 1994;6:47–60.
16. McCullock AJ, McCullock RM. Communicating shades: A clinical and technical perspective. Dent Update 1 999;26:247–252.
17. Sieber C. In the light of nature. Quintessence Dent Technol 1993;16:60–68.
18. Lemire P, Burk B. Color in Dentistry. Hartford, CT: Ney, 1975.
19. Preston JD, Ward LC, Bobrick M. Light and lighting in the dental office. Dent Clin North Am 1978;22:431–451.
20. Ray NJ. Some aspects of colour and colour matching in dentistry. J Irish Dent Assoc 1994;40(1):16–19.
21. Jun S. Communication is vital to produce natural-looking metal-ceramic crowns. J Dent Technol 1 997;1 4(8):1 5–20.
22. Rainwater C. Light and Color. Racine, WI: Golden Press, 1971:100–118.
23. O'Brien W. Double-layer effect and other optical phenomena related to esthetics. Dent Clin North Am 1 985;29:667–673.
24. Sproull R. Color matching in dentistry. Part I. J Prosthet Dent 1 973;29:41 6–424.
25. Preston J. Bergen S. Color Science and Dental Art. St Louis: Mosby, 1980:31–45.
26. Wozniak WT, Moser JB. How to improve shade matching in the dental operatory. Council on Dental Materials, Instruments, and Equipment. J Am Dent Assoc 1981;102:209–210.
27. Barna GJ, Taylor JW, King GE, Pelleu GB Jr. The influence of selected light intensities on color perception within the color range of natural teeth. J Prosthet Dent 1981 ;46:450–453.
28. Miller LL. Shade selection. J Esthet Dent 1994;6(2):47–60.
29. Hasegawa A, Ikeda I, Kawaguchi S. Color and translucency of in vivo natural central incisors. J Prosthet Dent 2000;83:41 8–423.
30. Smith PW, Wilson N. Shade selection for single-unit anterior metal crowns: A 5-year retrospective study of 2,500 cases. Int J Prosthodont 1998;11:302–306.
31. Scharer P, Rinn LA, Kopp FR. Esthetic Guidelines for Restorative Dentistry. Chicago: Quintessence, 1982.
32. Sproull R. Color matching in dentistry. Part III. Color control. J Prosthet Dent 1 974;31 :146–154.
33. Freedman G. Color communication. J Can Dent Assoc 1 994;60:695–699.
34. Williamson RT, Breeding LC. Make luster tabs for use in matching texture of porcelain surfaces. J Prosthet Dent 1 993;69:536–537.
35. Obregon A, Goodkind RJ, Schwabacher WB. Effects of opaque and porcelain surface texture on the color of ceramometal restorations. J Prosthet Dent 1981;46:330–340.
36. McLaren EA. Provisionalization and the 3-D communication of shape and shade. Contemp Esthet Restorative Pract 2000;(1):48-60.
37. Geller W. Polishing porcelain makes a crown smoother, more translucent, and improves the color. Quintessence Dent Technol 1 983;7:384–387.
38. Spitzer D, Ten Bosch JJ. The absorption and scattering of light in bovine and human dental enamel. Calcif Tissue Res 1975;17:129–137.
39. Hall NR. Tooth color selection: The application of colour science to dental colour matching. Aust Prosthodont J 1991 ;5:41–46.
40. Spear F. The art of intraoral photography. Seattle Institute for Advanced Dental Education. Seattle 1999:29–32
41. Pensler AV. Shade selection: Problems and solutions. Compend Contin Educ Dent 1998;19:387–396.
42. Jun S. Communication is vital to produce natural looking metal-ceramic crowns. J Dent Technol 1 997;1 4:15–20.
43. Fondriest JF. Improving photographic strategies in shade communication. J Cosmet Dent 2003; 19(3):70–74.
44. Rossing TD, Chiaverina CJ: Light science: Physics and the visual arts. 1999 Springer-Verlag, New York.
45. Polaroid Corporation Communiqué. Matching tooth color, subsurface characteristics using the Macro 5 SLR camera. Dental Products Report 2000;(Jan):46–47.