Malaysian Dental Journal (2013) Volume 35: Suppl. APDC

MALAYSIAN DENTAL JOURNAL

Color and Shade Matching: Significance in Dentistry

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ABSTRACT

The success of restorative dentistry is determined on the basis of functional and esthetic results. To achieve esthetics, one of the basic determinants is color. Color combinations not only improves esthetics but also makesthe restoration appear natural and attractive.Perceiving and analyzing color is a skill that can be taught and one that can be improved with practice. The knowledge of the concept of color is essential for achieving good esthetics. This review compiles the various aspects of color, its measurements and shade matching in dentistry.

Key Words: Chroma, Hue, Shade matching, Shade selection, Value

Please cite this article as: Bhatia S, et al. Color and shade matching: significance in dentistry. Malaysian Dental Journal 2013; 35(Suppl. APDC): 6-11.

INTRODUCTION

Esthetic dentistry imposes several demands on the artistic abilities of the dentist and the technician, therefore knowledge of the underlying scientific principles of color is essential.“Color is the result of the physical modification of light by colorants as observed by the human eye and interpreted by the brain” (Billmeyer and Saltzman). Of our five senses, vision is probably that which provides the normally sighted with the greatest amount of information about their surroundings and color plays a major role in this information gathering.[1]

Color combination not only improves esthetics but also makes the restoration appear natural and attractive. Color cannot be perceived without light, which is a form of electromagnetic energy visible to the eye.

PERCEPTION OF COLOR

Light

Color is all about light. For color to be seen, light is reflected from an object which stimulates the neural sensors in the eye’s retina to send a signal that is interpreted in the visual cortex of the brain.[2] The reflected components of incident white light determine the color of an object. Transparent materials allow for the passage of light with little change. Translucent materials scatter, transmit and absorb light. Opaque materials reflect and absorb; however, they do not transmit. Most of the color found in the natural tooth is established within the tooth. The semi translucent structure of tooth makes the color-matching procedure more complex when compared with an opaque object. Surface characteristics, such as gloss, curvature and texture, affect the degree of light diffusion when striking a particular object.[3]

Perception of color

As light enters the eye through the cornea and lens, an image is focused on the retina. The amount of light entering the eye is controlled by the iris, which dilates or constricts depending on the level of illumination. The retinal rods and cons can adjust the variation of light intensity.[4] Cones are packed tightly in the fovea region, which is the center of most acute vision, but rods are found away from the fovea and increase in numbers towards the periphery of the retina.

There are three types of cones, each containing a photosensitive pigment with a range of sensitivity to which it will respond. The pigments respond selectively to the additive primary colors of blue (445nm), green (535nm) and red (570nm), so the human visual system is able to receive color through the additive color system because the pigments convert light to color sensation. On the other hand, achromatic vision is mediated by the rods.[2]

Defective color vision
Normal color is called trichromatic vision as it is derived from three photosensitive pigments. Total color blindness (monochromatism) is extremely rare.The most common defects is when the person can see all three primary colors, but have a weakness or confusion in some area, usually the red or green area. There are also types of defects where the person can see only two of the primary colors. It is clear that color defects should be identified in dentists so that compensatory steps can be taken.[5] The important features that reflect color matching are contrast effects, and color constancy.[2]

Contrast effects: In this the background considerably affects the perception of color. Different contrast effects that alter the color vision are:

1. 1.Simultaneous contrast:the instantaneous change in chromatic sensitivity is characterized by a change in appearance of hue due to surrounding colors.
2. Actual contrast: the brighter tooth looks larger while darker tooth looks smaller.
3. Spatial contrast: the recessed teeth look darker while overlapping teeth appear brighter and larger.[6]

Color constancy occurs because we perceive certain objects as being of different color and the object seems to be of the same color even if the light received by the eye varies.[7] A neural response is involved in color vision and constant stimulation by a single color may result in color fatigue and decrease in the eye's response. Our ability to perceive color and visual acuity is also affected by aging, chronic illnesses, glaucoma and medications like oral contraceptives, ibuprofen, antiepileptic drugs, aspirin and antibiotics and lidocaine, etc.

EFFECT OF THE SURROUNDINGS

Color perception is affected by the reflection or interference from the surrounding colors. The effects of clothing and make-up, especially lipstick, should be neutralized. Negative after-image: The ability to perceive the correct hue is progressively diminished with time if one stares long enough. As light of a particular wavelength strikes the cones sensitive to the stimulus, the photosensitive pigments involved are depleted at a rate faster than regeneration can occur, making the eye less sensitive to the hue range of that stimulus. The accuracy of shade judgments becomes rapidly less reliable through this phenomenon termed "hue adaptation". Along with the waning ability to perceive a given hue, the eye becomes more responsive to the complementary hues of the adapted range. E.g. intense red lipstick can make teeth appear greenish by reducing red perception.

To overcome the problem in clinical situations, comparisons in shade selection should not exceed 5 seconds duration. The gaze should then be diverted to a card of a medium blue color to adapt vision to blue and sensitize it to the yellow color of the teeth. The eye can then continue to be an active receptor.[8]

Quality of light
The quality of light source is the most influential factor when determining tooth shade. The ideal light source is natural light, occurring around mid-day for accurate color comparison. The time of the day, month and weather conditions affect the color of sunlight. If the light source changes, then the light reflected from an object changes too; in that case, a different color is perceived. The absence of ideal conditions has led to the use of artificial lighting for color matching. The light source that approximates standard daylight is ideal for shade matching. Color temperature, spectral reflectance curves and Color Rendering Index (CRI) are all used to measure the capacity to reproduce standard daylight (CRI over 90 is recommended for color matching). Dental unit lights are usually incandescent lights that emit light high in the red–yellow spectrum and are low at the blue end. Regular cool white fluorescent lights are high in the green–yellow spectrum. Color-corrected fluorescent lights are also available, which render the color more accurately.[4] Full-spectrum light-

emitting diodes (LEDs) are now replacing incandescent bulbs. The shade-matching ability is better with a light-correcting source than under natural light.[9] A new device that eliminates the variability of different light sources, The OptilumeTrueshade," uses full-spectrum LEDs and shows a color spectrum similar to mid-day light. Diffusion lenses over the LEDs mix the three (RGB) colors of light emitted by the individual color diodes to create optimum, diffuse daylight. With the LEDs set at a 45-degree angle to minimize spectral reflectance or glare, the clinician can more accurately assess the true color.[7] A unique feature of OptilumeTrueshade is the ability to reduce the intensity of the light source while maintaining the color temperature. A lower-intensity light allows for better perception of surface details, such as topography, ridges and enamel striations.

Three dimensions of color

Color is usually described according to the Munsell color space in terms of hue, value, and chroma. Hue is the attribute of a color that enables the clinician to distinguish between different families of color, whereas value indicates the lightness of a color. Chroma is the degree of color saturation. When color is determined using the Munsell system, value is determined first followed by chroma. Hue is determined last by matching with shade tabs of the value and chroma already determined.[10]

Hue: is the quality of sensation according to which an observer is aware of the varying wavelengths of radiant energy. In Munsell's words, "it is the quality by which we distinguish one color family from another." The order of the physical hue is VIBGYOR, but within the visible spectrum, there is no clear demarcation between discrete lines. Hue is a physiologic and psychologicalinterpretation of a sum of wavelengths. The primary source of natural tooth color is dentine and its hue is either in the yellow or yellow-¬red range. In the Vita shade guide there are 4 hues:

- 'A" for reddish brown
- 'B" for reddish yellow
- 'C" for' greyish
- 'D" for reddish-grey

Chroma: is the dimension of color that defines the intensity or concentration of the hue. In Munsell's words, "it is that quality by which we distinguish a strong color from a weaker one." In teeth, it is dictated by the dentine and influenced by the translucency and thickness of enamel. Pale colors have low chroma whereas intense colors have high chroma. E.g. in the hue "A" of the Vita shade guide, A 1 has the lowest chroma, whereas A4 has the highest. Canines usually have higher chroma than incisors in the same mouth.

Value: is the relative blackness or whiteness of color.It is determined by gray on the value scale.On a scale of black to white, white has "high value", black has "low value" and midway between the black and white is medium grey Value is the only dimension of color that can exist by itself. Value differences are more noticeable and thus have more relative significance in a dental restoration than hue or chroma. In the hue "A" of the Vita shade guide A 1 is the brightest while A4 is the darkest.[11]

Evaluating dimensional differences

Color matching authorities state that hue differences are the easiest to detect and value differences the most difficult. In the evaluation of value and chroma differences, education and training are needed. Confusing value (degree of brightness) differences with chroma (color purity or saturation) differences is common. To test value differences, squinting is recommended. This eliminates detail and reduces the field of vision to a more achromatic (colorless) condition, making it easier to concentrate on value differences. When two objects are being compared they look more different during squinting than with normal viewing, a value difference is certain. Squinting is not a panacea for matching problems, but it provides a starting point that can be applied to clinical practice.

PROPERTIES OF COLOR

Translucency

Human teeth are characterized by varying degrees of translucency, which can be defined as the gradient between transparent and opaque. Generally, increasing the translucency of a crown lowers its value because less light returns to the eye. With increased translucency, light is able to pass the surface and is scattered within the restoration. The translucency of enamel varies with the angle of incidence, surface texture and luster, wavelength and level of dehydration.[12]

Fluorescence

Fluorescence is the absorption of light by a material and the spontaneous emission of light in a longer wavelength. In a natural tooth, it primarily occurs in the dentin because of the higher amount of organic material. Ambient near-UV light is absorbed and fluoresced back as light primarily in the blue end of the spectrum; however, it occurs at all wavelengths. The more the dentin fluoresces, the lower the chroma will be.[11] Fluorescent powders are added to crowns to increase the quantity of light returned back to the viewer, block out discolorations and decrease chroma. This is especially beneficial in high-value shades as it can raise value without negatively affecting translucency when placed within the dentin porcelain layers.

Opalescence

Opalescence is the phenomenon in which a material appears to be of one color when light is reflected from it and of another color when light is transmitted through it. A natural opal is an aqueous disilicate that breaks trans illuminated light into its component spectrum by refraction. Opals act like prisms and refract different wavelengths to varying degrees.[12] The shorter wavelengths refract more and require a higher critical angle to escape an optically dense material than the reds and yellows. The hydroxyapatite crystals of enamel can also act as prisms. Wavelengths of light have different degrees of translucency through teeth and dental materials. When illuminated, opals and enamel will transilluminate the reds and scatter the blues within their body; thus, enamel appears bluish even though it is colorless. The opalescent effects of enamel brighten the tooth and give it optical depth and vitality.

Metamerism

The change in color perception of two objects under different lights is called metamerism. Two objects with identical spectral distribution curves will always match regardless of the illumination. When attempting to create different materials with the same color, however, identical spectral distribution is difficult to achieve, resulting in metamerism. Tooth structure, porcelain and other tooth colored restoration materials have different spectral distribution curves; therefore should be tested under three light sources: daylight cool white fluorescent light and an incandescent lamp.[13]

Surface Gloss: Gloss is an optical property that produces a lustrous surface appearance, thus reducing the effect of color difference and increasing the brilliance.[9]

MEASUREMENT OF COLOR

Manual method: shage guides. Instrumental method: Colorimeters, Spectrophotometers and Spectroradiometer.

Shade guides

Early shade guides were derived from tooth colors that were considered pleasing rather than from the distribution of shades found in the general population. Clark introduced a custom shade guide in 1931 based on visual assessment of human teeth, recorded in Munsell Hue, Value and Chroma. A new generation of shade guides has been developed to address these deficiencies. Shofu offered the Natural Color Concept[14] while Vita introduced a 3-dimensional shade guide system (Vita 3DMaster). There is also Vita 3D-Master shade guide[2] which features a systematic colorimetric distribution of 26 shade tabs within the tooth color space.The shade guide is organized into five primary value levels, with a secondary distribution based on chroma and hue. These value groups are arranged from the lightest (value level 1) to the darkest (value level 5), left to right. The manufacturer advocates a three-step process: value is determined first in making a shade determination and then the chroma and hue are determined.

Limitations of shade guides:

- Does not cover the complete color space of natural teeth color.
- Shades are not systematic in their color space.
- Lack of consistency among the individual dentist in matching colors.
- None of the commercially available shade guides are identical.
- Quality control issues regarding color mismatches of shade tab and porcelain batches from the same manufacturer.

- Limitations of the instrumental method
- Translucency mapping is inadequate.
- Positioning of the probe or mouth piece seems to be critical to the repeatability of the measurement.
- Limited area is measured.
- Designed to measure flat surfaces.
- Prone to edge loss effects.
- Guidelines for shade selection.[11, 15, 16,17,18,19]
- Any color modification process like bleaching or micro abrasion should precede color selection after ensuring color stabilization.
- Stains and deposits must be cleaned off the tooth, and the tooth must be kept wet throughout shade determination.
- Shade evaluation must not be made after an aesthesia is administered, after tooth preparation is completed or after a strenuous appointment.
- Shade comparison should be made quickly.
- The eye should be rested by focusing on a gray-blue surface immediately before a comparison since this balances all the color sensors of the retina and resensitizes the eye to the yellow color of the tooth.
- Value, translucency, chroma and hue should be matched in that order.
- When in doubt, always select higher value and lower chroma, since it is easy to lower the value and increase the chroma.
- Hold the shade tab as close to the subject tooth as possible- incident light should hit both at the same angle.
- Cosmetic and bright colored clothes should be removed.

SHADE-TAKING DEVICES

Colorimeters

Filter colorimeters generally use three or four silicon photodiodes that have spectral correction filters that closely simulate the standard observer functions .These filters act as analog function generators that limit the spectral characteristics of the light that strikes the detector surface. These devices are considered inferior to scanning devices such as pectrophotometer and spectroradiometers. However because of their consistent and rapid sensing nature, these devices can be precise with differential measurements, this is why they are often used for quality control Shade Eyeis an example of a colorimeter based on the natural color concept.

Digital cameras as filter colorimeters

The newest devices used for dental shade matching are based on digital camera technology. Instead of focusing light upon film to create a chemical reaction, digital cameras capture images using CCDs, which contain many thousands or even millions of microscopically small light-sensitive elements (photosites). Like the photodiodes, each photosite responds only to the total light intensity that strikes its surface. To get a full color image, most sensors use filtering to look at the light in its three primary colors in a manner analogous to the filtered colorimeter described previously. There are several ways of recording the three colors in a digital camera.[20] Thehighest-quality cameras use three separate sensors, each with a different filter over it. Light is directed to the different filter/sensor combinations by placing a beam splitter in the camera. The beam splitter allows each detector to see the image simultaneously. The advantage of this method is that the camera records each of the three colors at each pixel location. The Shade Rite Dental Vision Systemand ShadeScancombine digital color analysis with colorimetric analysis, but pectroShadeis the only one that combines digital color imaging with spectrophotometric analysis.

Spectrophotometer and spectoradiometer

Spectrophotometers and spectroradiometers are instruments designed to produce the most accurate color measurements. Spectrophotometers differ from spectroradiometers primarily because they include a stable light source. There are two types of basic designs commonly used for these instruments. The traditional scanning instrument consists of a single photodiode detector that records the amount of light at each wavelength.3The light is divided into small wavelength intervals by passing it through a monochromator. A more recent design uses a diode array with a dedicated element for each wavelength. This design allows for the simultaneous integration of all wavelengths. Both designs are considerably slower than filter colorimeters. However, these arethe routinely used colormeasuring devices. Vita EasyShade is an example of a spectrophotometer.

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