The Nature of Color

Part 1 of 2

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Color is an essential ingredient in our environment and is associated with certain feelings, emotions and meanings. These associations are defined by the culture we live in as well as our personal experiences. Color communicates emotion, creates mood and affects energy; color has an emotional impact that can delight or distress. It is almost impossible to separate the seeing of color from the “feeling of color” because so much of what is seen is based on what is felt. Not surprisingly, these factors and influences have infiltrated into the oral healthcare environment with patients having a high expectation of a natural aesthetic result, both in the anterior and posterior dentition.

Although color as an entity should be regarded as only one of the many building blocks necessary in the achievement of an aesthetic result, nevertheless a discordant color scheme can probably be more devastating to the overall effect than many of the other factors present. It is for this reason that so much time, research and expense has gone into the “color matching” properties of contemporary aesthetic restorative materials.

Color matching and shade taking continues to provide oral health clinicians and technicians with one of the great and important challenges of their respective professions. Yet, despite the importance of color matching, this area still remains largely and universally untaught in most teaching institutions (Figure 1). A viable reason for color matching not to be part of a healthcare curriculum could well be the fact that all areas involved in healthcare, it occupies the unique position of requiring three equal elements for understanding and implementation. These elements could be defined and classified as scientific aspects, objective reasoning and subjective response.

Scientific aspects would involve understanding of the basic properties and nature of light and color, and an understanding of the physical and chemical properties of natural color as well as those of the object being studied. In dental healthcare this would involve the understanding of the anatomy and physiology of the various structures that make up the oral environment. A knowledge of the anatomy and physiology of the eye would be required, as well as a thorough understanding of color and image interpretation by the brain (Figures 2 & 3).

Objective reasoning would involve the understanding of the effects that various colors have on society generally and the individual specifically. There would be a scientific basis in that such an objective reasoning forms a part of psychophysics, psychology, philosophy and the morays and ethics of our contemporary religions. Although these aspects can be culturally and socially diverse, a unified pattern could nevertheless be established and reasoned, predictable “findings” applied. Subjective response is probably the least scientific of the three elements, yet possibly occupies the most dominant position. In order to achieve as near perfect color matching as possible, the subjective response needs to be disciplined in a positive and constructive fashion. In the fabrication of a single ceramic crown for example, three individuals are involved; the clinician, ceramist and the patient. Each individual will interpret color differently and success will be determined by achieving a consensus of approval for a particular shade. Attaining this consensus can often be a difficult and painstaking procedure, with possible remakes of the restoration commonplace. The scientific literature describes sexual and age differences in response to color stimulation, as well as cultural and ethnic differences. The manufacturers of aesthetic restorative materials have also inadvertently added to the challenge of accurate color matching. Although producing wonderful aesthetic materials, there still remains a lack of total standardization within the productive process and separate batches of the same material often display completely different color properties. The shade guide remains the traditional method of recording color matching, and for the most part this is totally inadequate as the guide is not unique to the chosen material.

The objective of this article is to present an understanding of the nature of color and to provide a simple road map technique that hopefully eliminates much of the uncertainty of color matching (Figures 4 & 5).

The Nature of Color

The modern understanding of color originated in the discovery of the spectral nature of light by Isaac Newton in the 1600s. Newton considered light to be a stream of particles. His experiments with prisms showed that white light can be split into individual colors. We now know that Newton’s famous experiments demonstrated that light consists of energies of different wavelengths. The universe is considered to be a magnetic field of positive and negative charges; constantly vibrating and producing electromagnetic waves. Each of these has a different wavelength and speed of vibration; together they form the electromagnetic spectrum. We can see about 40% of the colors contained in sunlight. So although white light appears colorless and intangible, it is made up of distinct color vibrations, which have not only wavelengths but also a “corpuscular structure”.

The Colors in Light

One way colors in sunlight are identified as red, orange, yellow, green, blue, indigo and violet. Each of these colors has a different wavelength, each is bent by a different amount. Rainbows are formed when water droplets in the sky act as natural prisms. As sunlight passes through the droplets, each of the different rays is bent by a different amount, creating a rainbow. The rainbow colors form one “octave” of light and are known as the “true hues”. Red is the longest wavelength we can see and it has the slowest frequency of vibration. Its magnetic energy is warming and stimulating. Violet has the shortest wavelength and the quickest vibration. It is cooling and cleansing (Figure 6).

Beyond the Visible Spectrum

At either end of the visible spectrum are many wave lengths we cannot see. Ultraviolet light is just beyond violet, and infrared light is just beyond red. Infrared light is found just beyond red light. Like red it has warming qualities although it gives off more concentrated heat; these
Fig. 11: Value scale and chart graduated from 0 to 10. A black or low value is represented by 0. White or high value with the mid-tones being grey.

Fig. 12: Chromatic scale, extending from weakly saturated on the left to densely saturated chroma on the right.

Fig. 13: Munsell Color Space. Vertical axis represents value extending from black on the bottom to white on top, with grey in the middle. The color wheel arranged around the axis represents the hues and chroma increases outwards and perpendicular to the vertical axis. Thus, hue, chroma and value can be observed at various combinations.

Fig. 14: CIE L’A*B’* scale. Lightness is calculated on the vertical or L scale and hue and chroma along the ab axis.

Fig. 15, 16 & 17: Variations in value in natural teeth. Low value giving a grey appearance, mid-value giving a cream appearance and high value giving a white appearance.

Describing Color

Color can be described in at least three different ways:
- Spectrophotometry describes the physical characteristics of a color (e.g., the spectral reflectance of a surface at different wavelengths).
- Colorimetry describes what a color matches with.
- The Munsell system describes what the color looks like.

The Munsell Color System

This system was proposed by the American All Munsell in 1905 and revised in 1945. The system defines three attributes of color: H (hue), C (chroma), and V (value). Color matching in dentistry is based on this system. Munsell established numerical scales with visually uniform steps for each of these attributes.

Hue is that attribute of a color by which we distinguish red from green, blue from yellow etc.

Munsell called red, yellow, green, blue and purple principal hues and placed them at equal intervals around a circle. He inserted five intermediate hues:
- Yellow-red
- Green-yellow
- Blue-green
- Purple-blue
- Red-purple

This makes ten hues in all.

Value indicates the lightness of a color. The scale of value ranges from 0 for pure black to 10 for pure white. Black, white, and the grays between them are called neutral colors. They have no hue.

Colors that have a hue are called chromatic colors (Figure 11).

Chroma is the degree of departure of a color from the neutral color of the same value. Colors of low chroma are sometimes called weak, while those of high chroma are said to be highly saturated, strong or vivid (Figure 12).

Munsell Color Space

Hue, value and chroma can be varied independently and the colors can be arranged in a three-dimensional space. The neutral colors are arranged in the vertical line called the neutral axis. Black is at the bottom, white at the top and all grays are in between. Hues are displayed at various angles around the neutral axis and chroma arranged perpendicular to the axis increasing outward (Figure 15).

CIE XYZ

In 1951 the CIE developed the XYZ color system, also called the “norm color system”. Red components of a color are placed along the X (horizontal) axis and green components along the Y (vertical) axis. Every color is assigned a particular point and the spectral purity of colors decreases as you move left along the coordinate plane. What is not taken into consideration in this model is brightness.

CIE L’A*B’*

A three-dimensional model with the color differences perceived corresponding to distances when measured colorimetrically. The a-axis extends from green (-a) to red (+a); b axis from blue (-b) to yellow (+b). Brightness (L) increases from the bottom to top (Figure 14).

Chromatic & Achromatic colors

Achromatic colors are white, black and grey in between. They lack the attributes of hue and saturation. Chromatic colors are everything else, we can have as having “color”; everything other than white, black or grey.

Color of the Natural Tooth

In describing the color of a natural tooth we find there are two additional attributes. In addition to hue, chroma and value, we discover the attributes of opalescence and fluorescence.

The definitions of the first three attributes are identical to those defined by Munsell, but each can be qualified further:
- Hue: The primary source of color is dentine and the hue of a vital, healthy tooth is in the yellow to yellow-red range.
- Chroma: In natural teeth the chroma is dictated primarily by dentine but is influenced by the translucency and thickness of enamel.
- Value: In a natural tooth the value is dictated primarily by the thickness of the enamel and the value is fixed.

Chromatic colors are then determined by the thickness of the enamel and the hue of the chroma is masked giving rise to a diffuse chromatic appearance.

Value: In natural teeth this is primarily influenced by the thickness of enamel.

The thicker the enamel, the greater the optical effects resulting in a higher value. Thick, dense, opaque dentine has the effect of lowering the enamel value (Figures 15, 16 & 17).

Opalescence: In a natural tooth, this is an effect produced in enamel and is due to different refractive indices of the various organic and inorganic components of enamel as well as the ability of hydroxylapatite crystal to scatter incident light. The result is that the long wavelengths are transmitted through the tooth whilst the short wavelengths are reflected, producing a bluish gleam. The effects vary from blue to grey to white gleaming areas (Figure 18).

Fluorescence: This effect occurs when a body absorbs luminous energy and then diffuses it back to the visible spectrum. In nature this is caused by ultraviolet light striking pigments in the dentine enamel interface resulting in light emission ranging...