Ceramic Materials and Color in Dentistry

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1. Introduction

The aesthetics of a dental restoration depends on the chosen material, anatomical form, surface texture, translucency and color. This means that, to accurately reproduce the appearance of a natural tooth, considering the patterns of reflection and absorption of the light is not an easy task (Knispel, 1991; Chu et al., 2004).
Ceramics have been widely used in dentistry because of their ability to provide excellent cosmetic results that mimic natural teeth. They are biocompatible, allow adequate reflection and transmission of light, and they exhibit good mechanical strength when subjected to masticatory efforts (Holloway & Miller, 1997). The rapid development of ceramic systems and processing enabled the treatment of teeth in both the anterior and posterior areas, with the primary objectives of properly restoring form, function and aesthetic excellence without the presence of metal.

2. History of dental ceramics

2.1 First porcelains

Ceramics are probably the oldest materials developed by man. Fragments of ceramic utensils, dated 30,000 years BC, helped archaeologists study the behavior of our ancestors. In 1774, the French pharmacist, Alexis Duchateau, dissatisfied with his dentures in ivory, noticed that the ceramic utensils used in handling chemical formulations resisted abrasion caused by the products used, and maintained their color. He suggested that porcelain could be considered as a possible replacement for missing teeth. Later, Duchateau, with the collaboration of a dentist named Nicholas Dubois De Chemant, managed to fabricate the first dental porcelain composition based on "green" traditional porcelain (50% kaolin clay or Chinese - $Al_2\,O_3\,SiO_2\,2H_2O$, 25 % feldspar - K2O $Al_2O_3\,6SiO_2$ and 25% silica or quartz - SiO_2). However, the prostheses made with these materials were abandoned due to their high opacity. In 1838, Elias Wildman made porcelain that was more translucent, with a brightness closer to that of natural teeth. This porcelain was of the Chinese pariana type, which is characterized by high translucency. The reduction or complete removal of the kaolin contents allowed an increase in the amount of feldspar, and therefore greater light transmission due to the absence of mullite, resulting in a migration of the porcelain composition from the mullite zone to the leucite zone. (Kelly et al., 1996).

2.2 Association of triaxial porcelain to metal

While providing a high translucency, feldspathic porcelain showed great mechanical fragility, attributed to its crystalline structure, when used in the mouth. Extensive prostheses made from pure porcelain fractures easily due to the propagation of cracks or defects resulting from laboratory processing (McLean, 2001; Sadowsky, 2006; Denry & Kelly, 2008). This clinical observation led to the introduction of metal infrastructures, associated with ceramics, in order to compensate for the low fracture resistance of the porcelain. This association became known as "metalloceramic prosthesis", and represents a milestone in the technological advancement of dental prostheses. From this event, dental porcelains could be used in extensive fixed prostheses, and a series of events took place after the introduction of these prostheses: improved techniques of ceramic processing, formulations of medium and high fusion porcelain and the introduction of vacuum electric furnaces.

The use of metalloceramic prostheses over the last 50 years has minimized the problem with porcelain fragility; however, its aesthetic potential was limited due to the presence of metal. The metal framework acts as a barrier to the transmission of light, giving the prosthetic dental restoration an unaesthetic opaque aspect, with the presence of darkening at the cervical region of the prosthetics. (Raigrodski, 2004).

2.3 Introduction of alumina as the ceramic reinforcing phase

In the search for a material to replace the metal infrastructure of a metalloceramic prosthesis, which presented a similar resistance while also associated the characteristics of aesthetic excellence, McLean and Hughes introduced aluminum oxide (Al_2O_3) as a reinforcing phase in dental porcelain in 1965. The incorporation of strengthening components to the feldspathic glass matrix enabled the construction of ceramic infrastructures without the presence of metal, initiating an era of advances in the development of new ceramic systems and processes routinely used in current dental offices. (Kelly et al., 1996)

The first ceramic infrastructures made of alumina were obtained by a process known as craft ceramic infiltration slipcasting, where an infrastructure of high-density crystal is prepared with a small amount of glass. The ceramic powder reinforced with alumina is mixed with water and applied over a refractory die. The resulting mass is sintered for 10 to 12hs at a temperature of 1140^{o}C. During sintering, the particles fuse and produce a crystalline structure which is opaque and provides low resistance. In a second stage, this structure is infiltrated by a thin layer of molten glass of low viscosity (lanthanum aluminosilicate). With an increase in temperature (1100oC for 4 to 6 hours), the glass melts and penetrates the infrastructure, through capillary action, and creates a ceramic surface with a very low porosity and high flexural strength. Three infiltrating systems (Vita Zahnfabrik, Germany) were developed for this technique of processing: reinforcing with alumina (70% to 85% aluminum oxide) and strengthening with magnesia (70% aluminum oxide and 30% magnesium oxide) or zirconia (67% aluminum oxide and 33% of tetragonal zirconium oxide). The flexural strength varies according to the reinforcement used: alumina (400MPa), magnesia (300MPa) and zirconia (750MPa). Depending on the strength achieved by the infiltration of the zirconia ceramic system, the construction of fixed prostheses in areas of high masticatory forces might be indicated. However, both the concentration of alumina and zirconia shown in these ceramic systems results in the impoverishment of the optical qualities of the restoration, due to its high opacity (Heffernan et al., 2002a, b). Additionally, the porosity incorporated during the manufacture of the infrastructure can affect the strength of these restorations (Miyazaki et al., 2009).

2.4 Improvement of glass-ceramics

Parallel to the introduction of infiltrated ceramics, glass-ceramics have been improved to be applied in the vacuum injection technique, similar to the traditional technique of metal casting. Two glass-ceramic compositions were introduced: leucite based (IPS-Empress, IvoclarVivadent, Liechtenstein) and lithium disilicate based (IPS-Empress 2, IvoclarVivadent, Liechtenstein). In the first composition, leucite is responsible for strengthening the ceramic, associated with the leucite resulting from the nucleation process (a phenomenon that occurs with increasing temperature), giving a higher flexural strength (120MPa) when compared to feldspathic porcelain, with the increased strength still not enough for extensive restorations. The great advantage of glassy systems is that they exhibit high light transmission, which allows the manufacture of prostheses with high aesthetic demands. In the second composition, the high content of crystalline lithium disilicate enables a volume increase of up to 60%. The crystals generated (elongated crystals of lithium disilicate measuring 0.5 to 5µm and lithium orthophosphate measuring 0.1 to 0.3µm) are smaller than those creased with the leucite reinforced ceramics, and their presence improves the flexural strength of the material (350 MPa), allowing the design of fixed partial prostheses of up to three units. (Heffernan et al. 2002).

The laboratory procedure for producing restorations using these materials consists in the inclusion of waxed patterns in conforming rings with a refractory lining. The wax is burned out in a conventional oven and then the rings are brought to furnace injection, where prefabricated ceramic inserts are melted and injected under heat (about 1150°C) and vacuum hydrostatic pressure (around 0.3 to 0.4 MPa). After the completion of the injection process, the molds are cooled to room temperature, and divestment is performed using jets of glass beads. The prosthesis of these systems can be obtained by two techniques: the restoration is cast in its final shape, and subsequently painted and glazed (the technique of makeup), or the ceramic infrastructure is obtained by injection, typically covered by a ceramic of a lower thermal expansion coefficient (layering technique).

2.5 Consolidation of CAD / CAM technology

The implementation of dental prostheses is a work of art. The dentist, as the potter, is responsible for the aesthetic outcome of the future prosthesis. In entirely handmade restorations, the possibility of errors is directly proportional to the number of variables involved (Miyazaki et al., 2009). The automation and the ability to fabricate ceramic prostheses using a machine-readable technology, design (CAD) and manufacturing (CAM), provide for the elimination of several clinical steps and a reduction of the variables inherent to the production of artistic work. With the CAD/CAM technology, all ceramic prostheses can be fabricated with an infrastructure of pure aluminum oxide (99.5%), which is crystalline, densely sintered and non-porous. The powder is packaged on a die in a refractory ceramic process known as vacuum uniaxial pressing (1600 1700ºC). The resulting piece has a flexural strength of 600 Mpa and a particle size of 4μ. Clinical procedures consist of obtaining a mold from the prepared area and preparing a die model. The die is positioned on the rotating platform of a scanner unit (CAD) and a probe with a spherical sapphire tip performs digital mapping of the die. The image obtained is sent to the system program, where the operator manipulates the generated image. The completed design of the digital infrastructure is sent via modem to a production station (PROCERA Sandvik®AB, Sweden or PROCERA® Fair Law, USA), where it is possible to industrially manufacture the piece requested (unit CAM). (Sadowsky, 2006; Miyazaki et al., 2009)

Other systems use CAD/CAM technology for machining ceramic blocks with diamond burs and discs. The restoration is carved in blocks of non porous ceramics of varying composition (feldspar, glassy, or aluminized reinforced with zirconia). A CAD unit (micro-camera or scanner) makes a digital reading of the prepared tooth (intra-oral version) or die gypsum (lab version), copying all of the details and transferring this information to a computer where the digital design of the infrastructure is performed. The chosen ceramic block is attached to the CAM unit and undergoes a process of attrition (milling) for about 10 to 30 minutes. The machining can be performed on pre-sintered or fully sintered blocks. The resulting pieces of pre-sintered blocks are shaped into a size 25 to 30% higher than desired (depending on the material batch) to compensate for the shrinkage due to sintering. Units from fully sintered blocks are machined in the ideal size, however, they suffer the stress of the machining process. (Luthard et al., 2004)

2.6 Structural ceramics based on zirconia

Zirconia (ZrO_2) is a ceramic which has been distinguished in the health field by its biocompatibility, bioinercy, high mechanical properties and chemical stability (Chevalier, 2006). Its use in dentistry is relatively new, however, and has proven to be a promising material for making prosthetic infrastructures for single crowns, crowns, bridges, abutments and implant prostheses (Denry & Kelly, 2008). Although there are currently several types of ceramic systems based on zirconia, the 3Y-TPZ has been the most studied and used in dentistry (Vagkopoulou et al., 2009). The polycrystal tetragonal zirconia stabilized with yttria (3Y-TPZ) contains 3mol% yttria oxide (Y_2O_3) as a stabilizer and was first applied in the medical field by orthopedists (Chevalier, 2006). For dental applications, the 3Y-TPZ is synthesized in small grains (0.2 to 0.5 mm in diameter), which minimizes the phenomenon of structural deterioration or destabilization in the presence of saliva, decreasing the subcritical crack growth (CST) (Denry & Kelly, 2008). Pre-sintered blocks are machined with the aid of CAD/CAM, and the specimens are then sintered. This processing reduces the level of tension present and prevents a tetragonal to monoclinic transformation (t → m), which leads to a final surface virtually free of the monoclinic phase. The infrastructure obtained from these blocks is more stable, having a high crystalline structure and a flexural strength around 900 to 1200MPa. Fully sintered blocks are processed by isostatic pressure at a temperature between 1400 to 1500 ° C. This process causes the block to achieve a final density close to 99%, high hardness and low machinability. Thus, robust machining systems must be used, resulting in the formation of a large amount of monoclinic zirconia due to the compression generated by the machining process, which usually results in microcracks on the surface and a susceptibility to degradation at low temperature (subcritical crack growth - SCG) (Kelly & Denry, 2008). Recently, in order to produce ceramic blocks with greater durability and stability under high temperatures and humid environments, the industry has introduced small amounts of alumina to 3Y-TZP, constituting a variation called TZP-A. However, a disadvantage of the addition of alumina is the reduction of the translucency of the final block (Yang et al., 2009).

2.7 Ceramic nanopowders

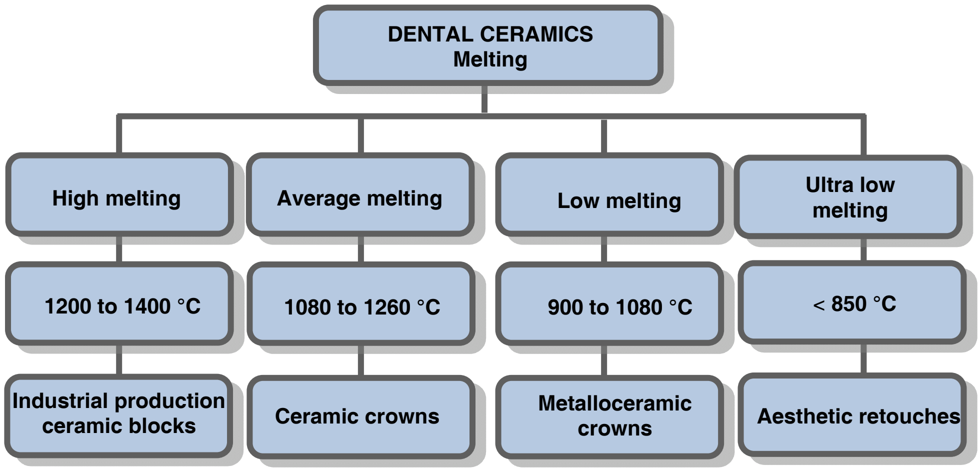
Nanotechnology is a collective term for a wide range of applications in structures and processes at the nano-scale. Nanoparticles are smaller than 1 to 100nm, and the atoms on their surfaces are very reactive. With the aid of these particles, it is possible to produce materials that are extremely rigid and resistant (Lamas et al, 1998; Tadakoro & Muccillo 2002). In the case of dental ceramics, this technology has enabled the preparation of nanopowders from zirconia-based ceramic (ZrO_2), alumina (Al_2O_3) and ceria (CeO_2). The resulting nanopowders have been used in the manufacture of industrial ceramic blocks for machining. With the introduction of these powders, the resulting block has a smooth surface, there is a considerable reduction of porosity and internal defects, and increased flexural strength (Yang et al., 2009). The optical properties have also been benefited because, as the nano-sized particles are well below the wavelength of light, they allow light to pass through the material. As handmade ceramics based on alumina and zirconia showed a high opacity; with the introduction of ceramic nanopowders, the current structural ceramics have begun to show an opacity subjected to laboratory control (Manicone et al., 2007).

3. Classification of dental ceramics

Didactically, dental ceramics can be classified by the melting temperature, composition and manufacturing process:

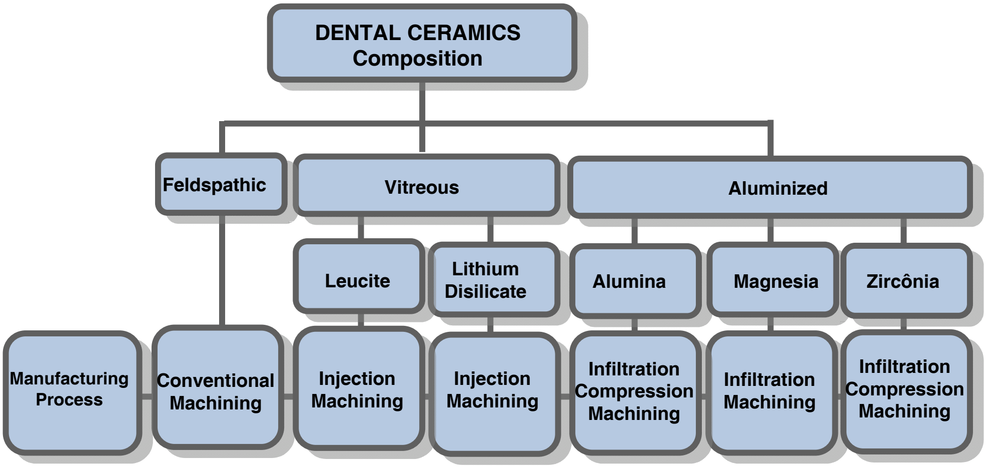
3.1 Melting

This classification was officially established in the 1940s and, more recently, fourth generation has been added, the ultra low-melting ceramics:



3.2 Composition and manufacturing process

Dental ceramics can be classified, according to their composition, into three distinct groups, which may be obtained by five different processes:



4. Understanding Color

4.1 Phenomenon of color

Color is a complex psychobiophisycal phenomenon resulting from the behavior of light through its wavelengths to the human eye. Color is not a property of the object, but of the light that enters our eyes from it. (O'Brien et al., 1989) Therefore, the real factor responsible for visual perception of color is the light. Without this, we can only see dark, or black. Light is an electromagnetic wave. Electromagnetic waves can be decomposed into multiple wavelengths, giving rise to a broad spectrum from radio waves (with wavelengths in kilometers) to the waves of cosmic rays (wavelengths less than 10 -13m). (Sproull, 2001). The region of light that reaches our eyes is called visible light. It includes the range of 400 to 700nm, and all the colors we know are within this range.

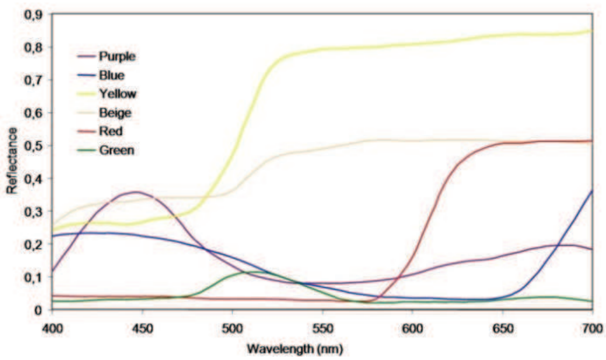


Fig. 1. Spectral curves of colors.
Source: Petter & Gliese, 2000

The color we perceive is a mixture of various wavelengths, and therefore, the color spectrum can be demonstrated from a graphic design known as the spectral curve or spectrum of color (Fig. 1) (Sproull, 2001b).

4.2 Physiology of color

Our eyes have two kinds of light-sensitive cells: rods, which are responsible for defining the shape of objects and night vision, and cones, which are located in the central area and are responsible for daytime vision, identification and differentiation of colors (Gliese & Petter, 2000). When light hits the eyes, it is immediately assimilated by the cells present in the retina. These cells are basically divided into three categories: those with greater sensitivity to red, green or blue; when light activates these cones, critolase, clorolase and cianolase pigments are synthesized, respectively. The amount of pigments produced results in X (red cones), Y (green cones) and Z (blue cones), with each resulting pigment responsible for a colorimetric stimulus. The three pigments generate messages that are simultaneously sent to the brain in the form of tristimulus (X, Y, Z) and, according to the concentration of each pigment, different colors of the object (primary and secondary) are displayed (Sproull, 2001). Described as an abstract science, perception of color involves the participation of three factors that can effectively exist: (Gliese & Petter, 2000; Joiner, 2004)

- **Object to be observed:** The object being viewed may have different physical behaviors in relation to the incident light. If an object is transparent, it acts as an absorbing environment by allowing light to pass through it (light transmission) and allowing us to see through it. If an object is translucent, some light passes through the object and part is reflected, allowing our perceptions regarding the color of that object. If the object is opaque, the reflection of light occurs in a diffuse way, which is responsible for the colorimetric awareness of our eyes (Fig. 1) (Knispel, 1991). Likewise, if the object absorbs all incident light, there is no reflection, and then we will see a dark color or black. If the object completely reflects the incident light, our vision will identify a white object. However, if part of the light energy is reflected and part is absorbed, the display is a colored object. (Joiner, 2004).

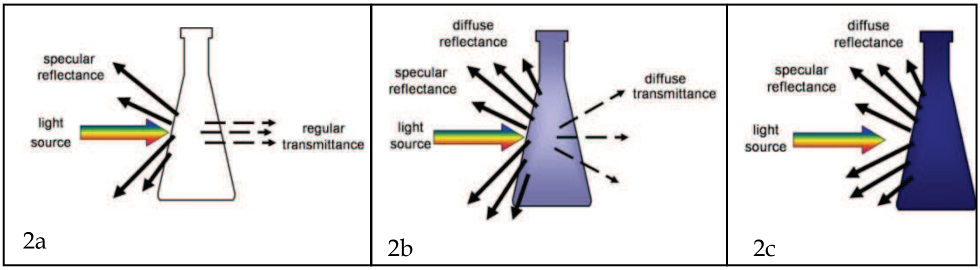


Fig. 2. Light behavior in transparent(2a), translucent (2b) and opaque objects (2c).
Source: Petter & Gliese, 2000

- **Observer:** The observation of an object can be in a visual or an instrumental way. In a visual analysis, the perception of color is a subjective process and the interpretation depends on the observer's visual individuality. If the observer is an individual trained in the analysis of color, they can identify subtle differences in color. Changes in color perception may occur based on age, duration of exposure of the eye, fatigue or illness related to color, such as color blindness. (Van Der Burght et al., 1990). In instrumental analysis, colorimetric instruments objectively observe and record color. Two types of equipment have been used: colorimeters and spectrophotometers. Colorimeters analyze the values for red, green and blue reflected through filters that simulate sensing photoreceptor cells of the human eye. The tristimulus X, Y and Z coordinates are automatically converted to L*, a*, b* values of the CIE L*a*b* system. (Gliese & Petter, 2000). Spectrophotometers measure and record the amount of light reflected or transmitted from the object through its wavelength. These devices have high precision, sensitivity to measure absolute colors and are equipped with spectral distributions of various illuminants. The most accurate spectrophotometers are those of integrating spheres, called spherical optical, in which the object is exposed to light at different angles and directions for its analysis. (Paravina, 2002).

- **Light source or illuminant**: The illuminant may be a natural or artificial light source, which, according to its origin, can change the perceived color of an object. For example, a white sheet of paper may seem bluer under fluorescent light and more yellowish under a light bulb, returning to its original color in the presence of daylight. This phenomenon is known as metamerism. (Knispel 1991). Aiming to standardize the visual and instrumental analysis of color, the International Commission of I'Eclairage (CIE) has classified illuminants according to their effect on the perception of color. The CIE appointed 3 standard illuminants: A, B and C. Later, the illuminant series D, the hypothetical illuminant E and unofficially the illuminant series F were added (Chu et al., 2004):

Illuminant	CIE definition
A	Tungsten light source with an average temperature of 2,856 K, which produces a reddish-yellow light. Generally used to simulate conditions of incandescent light.
B	Tungsten light source coupled to a liquid filter to simulate direct sunlight with an average temperature of 4,874 K.
C	Tungsten light source coupled to a liquid filter to simulate indirect sunlight with an average temperature of 6,774 K. However, it is not a perfect simulation of sunlight, because it contains a large amount of ultraviolet light needed in the analysis of fluorescence.
D	Series of illuminants representing different conditions of the day. Illuminants D50 and D65 (so called due to temperatures of 5,000 K and 6,500, respectively) are generally used as pattern illuminants and match the reflectance of blue light.
E	It is a theoretical light source, in which an equal amount of energy would be present at all wavelengths. Currently this illumination does not exist, but this value is used as a tool for scholars of hypothetical colorimetry.
F	It involves a series of fluorescent lights. Fluorescent lamps have peaks that are evident in their spectral curves and do not fit the color temperature, therefore, are not considered an officially illuminating pattern. However, as the fluorescent display is widely used, the CIE recommends these illuminations to evaluate colors observed in the fluorescent environment.

Table 1. Series of illuminants

4.3 Colorimetric parameters

In 1936, Munsell (O'Brien et al., 1989) described the three dimensions of color to opaque objects: hue, chroma and value. This language became known worldwide; therefore, it became important to understand the color three-dimensional concept to perform visual and instrumental analysis.

- **Hue or tint:** the first attribute by which a color is identified and distinguished, or the name of the color: blue, yellow, red, green, among others. It corresponds to the wavelength of light reflected by the objects. (Fig. 3) (Sproull, 2001).
- **Chroma or saturation:** indicates the purity of the color, quantifying its saturation. The lighter a color is, the lower its saturation. Moreover, saturation increases as the object is darker. For example, red is a saturated hue, while pink is the same hue, but less saturated. (Fig. 4) (Sproull, 2001).
- **Value or light intensity:** the property which is distinguished by the lightness or darkness of a color. The clearer the color, the greater its value (brightness) and the darker, the lower the value. A good example is the brightness of full white, represented by the maximum value on the intensity scale (100), while black shows the absolute value of 0, or the total absence of light. (Fig. 5) (Sproull, 2001).

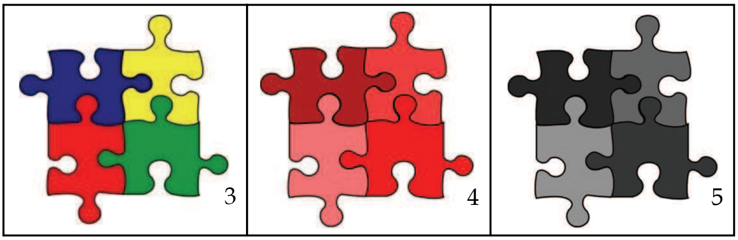


Fig 3. Hues blue, yellow, red and green.
Fig 4. Saturation of the hue red.
Fig 5. Values of light intensities or saturations shown in Figure 3.

4.4 Color space CIEL*a*b*

To improve the precision in color communication of an object, the International Commission of I'Eclairage (CIE) has developed some methods to express the spectral curves in a numerical form. The method used in dentistry is the uniform color space, known as CIEL*a*b*. (Fig. 6) (Rosenstiel & Johnston, 1988). Color space is a numerical area that expresses and references the object's color. Here, L* indicates the lightness coordinate of the object, with values from 0 (absolute black) to 100 (absolute white). The values a* and b* indicates the chromaticity coordinates, showing the three-dimensional position of the object in the color space and its direction. When the coordinate a* is positive (+a*), the object color tends to red. When this coordinate is negative (-a*), the trend is green. This coordination can range from -90 to 70 Δa*. The coordinate b* indicates the direction to yellow (+b*) or blue (-b*), and can vary from -80 to 100 Δb*. (O'Brien et al. 1989; Barath et al., 2003).

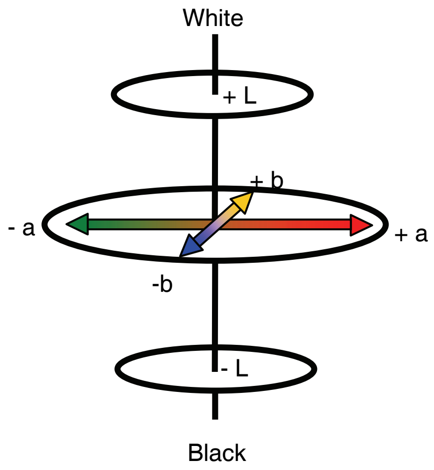


Fig. 6. System CIEL*a*b*
Source: Barath et al., 2003

The achromatic values of color are represented in the axis of lightness (L*), while the spatial projection of data color is presented on the axes of chromaticity (a* and b*) allowing the conceptualization of the components of the chromatic color changes. (Knispel, 1991). The values of the coordinates L* a* b* are obtained from the tristimulus X, Y and Z (generated by light reflected from the object observed) from the following equations, where the values Xn, Yn and Zn correspond to white (Gliese & Petter, 2000):

$$L^* = 116\,(Y/Y_n)^{1/3} - 16 \quad (1)$$

$$a^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}] \quad (2)$$

$$b^* = 200[(X/X_n)^{1/3} - (Z/Z_n)^{1/3}] \quad (3)$$

The space between two colorful points is calculated as a color difference (ΔE). The magnitude of this difference can be obtained by the following equation (Gliese & Petter, 2000):

$$\Delta E = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{1/2} \quad (4)$$

Where:

$$\Delta L^* = L^*1 - L^*2 \quad (5)$$

$$\Delta a^* = a^*1 - a^*2 \quad (6)$$

$$\Delta b^* = b^*1 - b^*2 \quad (7)$$

4.5 Clinical significance

As the final judgment of colorimetric evaluation is visual, it has been necessary to establish a relationship between visual and instrumental analysis. In the classic work of Kuehni & Marcus (1979), color differences between samples 1ΔE were perceived and judged acceptable by 50% of observers under ideal conditions of illumination. From this work, Johnston & Kao (1989) assessed this relationship in dentistry. Since there is difficulty in controlling light conditions in the oral cavity, an average difference of up to 3.7 ΔE was considered acceptable by those authors, who suggested an extended visual rating scale (EVRSAM) to understand the clinical significance of the numerical results of instrumental analysis evaluation of color for dental materials.

ΔE	Clinical significance.
0	Excellent esthetics with accurate color choice, not being clinically perceived, or only with great difficulty.
2	Very slight difference in color, with very good aesthetics.
4	Obvious difference, but with an average acceptable to most patients.
6	Poor aesthetics, but within the limits of acceptability.
8	Aesthetics are very poor and unacceptable to most patients.
10	Aesthetics are totally unacceptable.

Table 2. Extended visual rating scale (EVRSAM)
Source: Johnston & Kao, 1988

5. Behavior of color on natural teeth

The color of a tooth is determined by a combination of intrinsic and extrinsic colorimetric effects. The intrinsic properties color are associated with the reflection and absorption of light; with the extrinsic properties related to coloring materials interacting with enamel, such as coffee, tea, tobacco (Chu et al., 2004). When light falls on a natural tooth, four associated phenomena can be described: the transmission of light through the tooth, specular reflection from a tooth's outer surface, diffuse reflection of light from the buccal surface, absorption and scattering of light in the dental tissues. Factors such as enamel thickness, shape, surface texture, dominant color of dentin, double layer effect and light source may further complicate the visual perception of the various nuances of the whole tooth. (Joiner, 2004).

6. Physical characteristics of dental ceramics

6.1 Color stability

The lower the degree of porosity evidenced by a ceramic after laboratory processing, the higher its color stability. This means that industrially manufactured ceramic prostheses show greater color stability when compared to hand crafted prostheses. However, variables, such as the use of extrinsic dyes, number of firings, association with vacuum, type of ceramic material, presence of metal framework and thickness of the ceramic materials, can influence the color stability of ceramics (Brewer et al. 1985; Kourtis et al., 2004).

6.2 Translucency and opacity

Paradoxically, dental ceramics should present both translucency and opacity to mimic dental structures. The opacity is directly related to dentin, because the light passes through enamel and reaches dentin, which, as an opaque body, reflects the light again. On the other hand, enamel behaves like a translucent object, allowing the passage of light, which permits visualization of the dentin while also providing the scattering of light at a wavelength of blue through its hydroxyapatite crystals (Joiner, 2004). There is no ceramic dental product that can simultaneously display characteristics of opacity and translucency in a single material. Therefore, manufacturers have offered ceramics for infrastructure building, opaque ceramic coverage for the construction of the dentin and translucent glazes to be used in layering techniques (Heffernan et al., 2002 a, b).

6.3 Fluorescence

Some substances have capacity to absorb the energy of a non-visible light (ultraviolet, cathode rays or X-rays) and turn it into a visible light, ie light with a greater wavelength than the incident radiation. (Vanini, 1996). When natural teeth are exposed to ultraviolet (UV) light, fluorescence is observed, with an emission spectrum band ranging from white to intense blue light with a wavelength shorter than 400nm. The responsibility for this phenomenon falls with dentin, which has a much more intense fluorescence than enamel (three times more fluorescent), due to the presence of a greater amount of UV photosensitive organic pigment. In order to mimic the behavior of this optical phenomenon, some dental ceramics exhibit fluorescent characteristics similar to teeth in order to create an effect of luminosity. Rare earth metals (europium, terbium, cerium and ytterbium) have been used as luminophor agents in the composition of ceramic powders, because they show an intense blue-white and yellow fluorescence. When a ceramic dental material is not fluorescent, it tends to have an appearance of reduced vitality, presenting a grayish appearance, especially in dark or black lights (Monsenego et al., 1993).

6.4 Opalescence and counter-opalescence

There are properties of transparent or translucent materials which gives those materials a milky appearance, with iridescent reflections that resemble opal stone. This optical phenomenon is attributed to the enamel, as it is a highly mineralized tissue. Enamel acts as a filter and has the ability to selectively forward the long waves, while at the same time, reflect the short waves. Because of this reflection, incisal enamel can be viewed as having a bluish-white color. When long waves that were being transmitted relate to dentin and are reflected back, they give enamel an orange glaze (an effect known counter-opalescence). In ceramics, the effects of counter-opalescence and opalescence are obtained by using different opalescent glazes. Some have a bluish color and others an orange color, depending on the addition of pigments to the ceramic powder. At the time of construction of the prosthesis, the lab tech stratifies enamel into layers, according to the optical nature of the tooth, ensuring the combination of aesthetic effects with regards to fluorescence (Cho et al., 2009).

7. Behavior of color in dental ceramics

7.1 Optical influence of the illuminant

The light source has been identified as one of the factors that most influences the choice of color (Dagg et al. 2004). The type of light source, its intensity and inclination are some of the variables cited in the literature (Barna et al., 1981, Dagg et al. 2004). Due to the three-dimensional nature of color, the behavior of light has been studied; however, its complexity creates a variety of questions of when to use a specific light source. Metamerism is largely responsible for distortions in the selection of color, thus adopting rules to minimize this effect may help in the optical outcome of the ceramics used. As color selection is usually performed under an indirect natural light source, it is prudent to involve fluorescent and incandescent light sources for the selection of color and the evidence of ceramic prosthesis in minimizing landmark metamerism (Volpato et al., 2009).

7.2 Optical influence of the substrate

The type and color of a substrate must be considered when selecting a restorative material, because they influence the final shade of ceramic restorations, mainly with glassy systems. When a substrate has a color similar to the ceramic, the recommended thickness (about 1.5 mm) can be used for vitreous systems. Ceramics, with high translucency and when using layering techniques (such as glass-ceramics based on lithium disilicate), can be fabricated on darkened substrates, such as posts and metal cores, since the dental preparation offers a larger space (about 2.0 mm) (Volpato et al., 2009). However, if this space is not available, systems with a ceramic infrastructure should be used (infiltrated, compact or machined systems), because they are able to provide enough opacity to mask these substrates under a reduced material thickness. (Heffernan et al. 2002b; Koutayas et al., 2003).

7.3 Optical influence of material thickness

The amount of dental reduction while performing the preparation determines the space required for the production of ceramic prostheses. Each ceramic system should ensure that this thickness does not compromise the emergence profile of the restorative work. However, as mentioned above, preparations are not always made on substrates that have a similar color as the tooth. In prostheses with favorable substrates, it is important to communicate the color of the ceramic substrate when fabricating the prosthesis based on this background (Dozic et al., 2003). However, if the substrate is not favorable, it is ideal to utilize more room for the glass-ceramics or to associate infrastructures that provide a degree of opacity that may block the arrival of light to the substrate. Achieving a deeper preparation can improve the ability of a ceramic to hide the substrate, as increasing the thickness of a ceramic material decreases the degree of translucency. (Vichi, Ferrari, Davisdon 2000; Carossa et al., 2001, Nakamura et al. 2002; Dozic et al. 2003, Volpato et al., 2009). However, care must be taken so that wear of the ceramic does not compromise the mechanical properties that are necessary for the dental preparation.

7.4 Optical influence of material composition and manufacturing process

Based on the variety of ceramics available, it is important to understand that the composition and manufacturing process directly influence the optical outcome of the prosthesis produced, and are important factors for the aesthetic success of the case. For maximum reflection and opacity, the ceramic particles should be slightly larger than the wavelength of light and have a different refractive index of the array where it is incorporated, as a higher refractive index of a material produces greater opacity. (Heffernan et al., 2002a). Ceramic systems using alumina or zirconia have high refractive indices and are therefore used as opacifying elements (Vagkopoulou et al., 2009).

8. Methods of color selecting in Dentistry

8.1 Visual analysis of color

Traditionally, the visual perception of color is the most commonly used selection method in dentistry. This subjective method is based on standardized scales that are composed of representative samples of the average of the colors present in the human dentition. Through this shade guide, you can perform a visual comparison with natural teeth. (Segui et al., 1989). Color selection using scales is extremely complex because the selection process may be influenced by variables ranging from the interpretation of three-dimensional nature of color, to environmental influences. Selections may be inadequate due to factors such as fatigue, age, stress, prior exposure of eyes to light, the observer's visual individuality, inappropriate positioning of the object and an illuminating influence from the environment, and metamerism. Moreover, the human eye can detect small differences in color, but the ability to communicate these differences in terms of magnitude and nature of the difference is very limited. (Knispel, 1991). Despite being widely publicized, prefabricated scales are not representative of the wide range of colors present in natural teeth. These colors are not systematically distributed in the CIEL*a*b* system. Additionally: the material available for use in the dental clinic and laboratory is not the same as the material used in the scales; the thickness of the teeth in the scale does not simulate the clinical condition; most scales have no metallic or ceramic infrastructure; the degree of translucency of the incisal portion; and the characterizations and pigmentation in the cervical third of the scales all make comparison with natural teeth very difficult. These factors may necessitate the observer to get used to a single scale in order to avoid errors during the visual selection of color (Sproull, 2001b).

As color scales have limitations, some factors should be observed to improve their use: the selection of color must be performed at the beginning of the procedure, when the teeth are not dehydrated and the professional is not tired; the color scale should be kept on the same plane of the lower anterior teeth so that light falling on them can be reflected in the same plane to the observer; the scale and teeth should be slightly moistened to facilitate the reflection of light; the operator should look for a maximum of 10 to 15s at each hue and rest by looking at a neutral gray background between observations; the patient should be prepared with a protective clear color so that the color of their clothes does not confuse the operator; the environment must provide the quantity and quality of indirect natural light, usually between 11 and 14 o'clock; and finally, the optical behavior of the color chosen should be reassessed with different artificial illuminations (eg, incandescent light and fluorescent light), in search of a remarkable metamerism that can derail the chosen color. (Chu et al., 2004)

Fig. 7. Visual selection of color – value
Fig. 8. Visual selection of color - hue and chroma

8.1 Instrumental analysis of color

Colorimeters and spectrophotometers have been used in dentistry for the determination, quantification and comparison of color in the industrial manufacture of materials. Instruments have been designed for clinical use, in order to select the color in the mouth and transmit the data to a laboratory, controlling the result for direct and indirect restorations, tooth whitening, and to minimize subjective visual perception. (Sproull, 2001b). Just as in visual analysis, care must be taken during the selection of an instrumental color: the teeth should be clean and dry for capturing the color, as the presence of plaque and saliva may affect the actual color registered by the equipment; the probe should perpendicularly touch the selected area; and a minimum of three readings should be performed at the cervical, middle and incisal thirds of dental tissues. (Chu et al., 2004)

Fig. 9. Instrumental selection of color
Fig. 10. Results obtained by oral spectrophotometer

9. Color Communication

The precise communication of color is one of the most important requirements for achieving excellent aesthetic work. This can be achieved by joining two ways: chromatic maps and digital photos.

9.1 Chromatic maps

Since teeth are composed of different shades of color and optical effects, it is necessary to identify: the predominant color (middle third), areas that differ from the predominant color (cervical and incisal), and the presence of translucent areas, fluorescent effects opalescent effects, and mamelon spots. All of this information must be recorded correctly on a map. These chromatic maps are efficient documents in communicating color variations to the laboratory.

9.2 Digital Photos

Digital photos can be used as a reference for color selection; therefore, they are excellent methods of communication with the laboratory, especially when the laboratory technician is not in the same town as the dentist and patient. The photograph should be taken with the tooth and the scale color that was chosen. If translucent ceramic is to be used in restorations for the rehabilitation of a patient, it is important to photograph the prepared teeth with the color scale in position to inform the lab tech of the substrate color. Translucent areas are best assessed on photographs taken with a black background, because it prevents reflected light from the mouth to strike the enamel again.

Image-editing programs can be used to analyze color dimensions and characteristics of shape and texture. A photo can be digitally converted into grayscale, because value is the quality (not quantity) of the gray color, a colored object photo in grayscale will be the image of its value. Thus, it is possible to compare the value of the scale with the natural tooth, confirming the selection of value. Another process that can be performed is to increase the contrast (+50%) and decrease the brightness (-50%) of the digital photo. The resulting image will enable the display of translucent areas, the precise format of mamelons, the presence of an opalescent halo at the incisal edge, and white spots and cracks, because this is valuable information for the lab tech in the construction of the prosthesis. (Miyashita, 2005)

Fig. 11a, b. Original photo and grayscale to view the value.
Fig. 12a, b. Original photo and increase the contrast and brightness of the digital photo.

10. Conclusion

Since the introduction of metal ceramic crowns, clinicians and researchers have been looking for a restorative system that can associate beauty, strength and durability, but without the presence of a metallic infrastructure. Indeed, dental ceramics are materials that come aesthetically closest to natural teeth. With the improvement of ceramic systems, it has been possible to combine the excellent aesthetic characteristics of this material with a considerable resistance to fracture. It is imperative to understand the phenomenon of color and its variables in the oral cavity, as well as associate different techniques of color selection and communication, in order to get prostheses that look closer to natural dental tissues.

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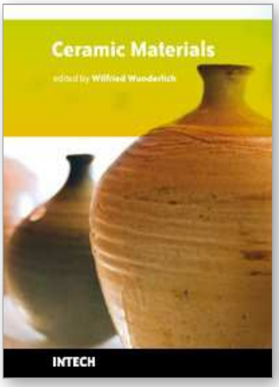

Ceramic Materials

Edited by Wilfried Wunderlich

ISBN 978-953-307-145-9

Hard cover, 228 pages

Publisher Sciyo

Published online 28, September, 2010

Published in print edition September, 2010