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# The Color Stability of Aesthetic Orthodontic Brackets. Review of applications and research aspects

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**Abstract:**
was to review the current status of color measurement application in the study of the color stability of aesthetic orthodontic brackets and corresponding researches.Google scholar database from 1970 to 2017 were searched electronically with key words: Aesthetic brackets, Color stability, Spectrophotometer.It was concluded that Spectrophotometers and imaging systems are useful and relevant tools for Color Stability of Aesthetic orthodontic brackets, and they are best choice to determine the color change of aesthetic brackets in clinical use. The ceramic bracket is better than any other aesthetic bracket in color stability property.

## Introduction

This article is A review of color measurement applications on the Color Stability of aesthetic orthodontic brackets. The article theme is an understanding of the principles of color measurementwhen studying the color stability of aesthetic orthodontic brackets. In order to obtain attractive smile during orthodontic treatment and achieve patient expectations.

Orthodontic treatment aims at providing an acceptable functional and esthetic occlusion.[1]the appearance of the orthodontic appliances has always been of special interest in the orthodontic treatment.[2]On the other hand, the aesthetics in fixed orthodontic appliances is a common problem and inescapable challenge to all orthodontists. If it is done, the orthodontist is considered to be successful by patients. To this end, many different types of materials have been introduced to serve better aesthetics for orthodontic applications.[3]

The demand for aesthetic orthodontic appliances is increased, particularly among youth patients who are more concerned about their appearance during orthodontic treatment. Furthermore, demand to orthodontic treatment between adults has increased, thus, appearance of esthetic brackets has been a blessing for those patients.[4]Therefore the advent of esthetic brackets made orthodontic treatment a viable option for a large segment of the people that had previously found orthodontics to be esthetically unacceptable.[5]

Day after day, there is a wide difference in the aesthetic brackets available in orthodontics. The optical property of these materials in terms of color stability.[6]The color stability of these esthetic brackets has remained the main concern for clinicians as well as patients. There are two types of discoloration of esthetic brackets: Internal (endogenous) due to the ultraviolet irradiation and thermal energy.[7] The external discoloration is chiefly due to color dyes, such as food dyes, tea stains, Soft drink, etc.[8]

Color difference values and coordinates of color is varying by method of measurement. The human eye sensitivity in observing small color differences is very limited and interpretation of visual color comparisons is subjective. Therefore, spectrophotometer is necessary to allow reproducible results of color determination.[9]

## Esthetic Brackets

### a. Plastic brackets

The initial aesthetic brackets emerged during the 1970s and they were made from plastic and polycarbonate materials [10] , Early attempts to make the appliance more aesthetic in appearance resulted in the introduction of plastic brackets that first reported by Newman [11] . who examined many plastic materials such as nylons, acrylics, epoxies, polycarbonates, Polysulfones, and polyphenylene oxides. He established that the polycarbonates were the most appropriate for orthodontic attachments for several reasons such as: Polycarbonate is approved by the FDA (Food and Drug Administration) and it is nontoxic, it is relatively easy to fabricate into precision small parts such as brackets, it has good abrasion resistance, it has high impact strength, it is odorless and tasteless and It is resistant to deformation under stress.

However, Newman found that, like all plastic materials, polycarbonate absorb moisture, even minimum water absorption is associated with a dimensional change [11]. The moisture absorption quantity increases with time and temperature until an equilibriumof moisture content occurs. Moreover, water absorption of Plastic brackets could induce a plasticizing effect which declines the properties of the polymeric structure in moist environments.Therefore, further efforts are necessary to improve the mechanical properties of plastic brackets. [12][13]

Aird and Durning found that 7.4 % of the examined polycarbonate brackets were fractured during orthodontic therapy, primarily within the tie-wing, and tended to be stained, thereby Compromising aesthetics [14]. Although plastic brackets were introduced with considerable enthusiasm, Proffit[15] and Winchester [16]reported that, they are not durable enough to hold up in the mouth in the long term because of the following problems : Staining and discoloration, particularly in patients who smoke or drink coffee , Wear of the brackets and tie-wing fracture ,Absorption of water and saliva , Poor torque control of teeth, permanent deformation under torque force stresses and Friction between the plastic bracket and metal archwires that makes it very difficult to slide teeth to a new position.

Feldner et al [17] reported that, after multiple clinical trials, flaws in the physical properties of plastic brackets became apparent and their popularity decreased. Moreover Dobrin[2]found other problems reported included crazing and deformation as well as stains and odors. Also, the artificial aging of plastic brackets has a plasticizing effect on the bracket, attributed to water absorption, which is considered to reduce its torque capacity. Also, Faltermeier[9] has established that drinking of tea and coffee may cause undesirable color changes in plastic brackets.

For recompensing low strength and rigidity of initial poly-carbonate brackets, high grade polyurethane brackets strengthened with ceramic or fiber glass fillers or metal slots, resulting in the so-called “composite” brackets, as well as the development of new polymer types [17] . Nevertheless, these problems have not yet been completely resolved [18]. Although, composite brackets are made up of polycarbonate which adsorbs water during orthodontic treatment, it remained the most popular option preferred by the patients.[19]

### b. Ceramic brackets

They were first made in late 1980s with aiming to overcome esthetic problem in metal brackets and disadvantages of Plastic Brackets. The early appliances exhibit significant clinical and esthetic progresses owing to their shade stability and resistance to oral fluids.[20]

It was available for orthodontic applications nearly 10 years after the development of ceramic brackets [21] . Recently Swartz found that some problems encountered in plastic brackets were eliminated through the development of ceramic brackets which were first introduced in 1987 as a more esthetic alternative to their plastic predecessors.[22]

Although ceramic brackets enhance the appearance of fixed appliances, they are still far from ideal in fulfilling the requirements of orthodontic brackets [23]. Even if esthetics is the advantage of ceramic brackets in relation to metal brackets. Some researchers reported that , the color of these brackets changes in mouth environment because of staining from substances containing pigments present in drinks and food [24],but other than that Arici and Regan reported that the advantages of ceramic brackets involve color stability and great strength. [23]

Kusy and Whitley[25]reported that ceramic orthodontic brackets showed increased friction compared with metal brackets. Also, increasing usage of sliding mechanics that followed emergence of pre-adjusted edge-wise systems gives great attention to the influences of friction among brackets and arch wire and its impact on resistance to tooth movement.

Drescher et al mentioned, that friction responsible for 60 percent of the force needed for creating movement of tooth in many bracket / arch-wire combinations [26]. A bracket system with a little frictional resistance resulted in self-ligating brackets development. despite the first self-ligating bracket was Russell-lock, orthodontists and manufacturers shown more interest in the progress of self-ligating brackets since 1970s [27, 28].

Ceramic brackets are composed of a broad class of materials consisting of metal oxide elements and non-metal elements that include precious stones, glasses, clays and mixtures of ceramic compounds. Alumina ($Al_2O_3$) is a typical example of modern ceramics, others include zirconia ($ZnO_2$) and combinations of both materials.[29]

The Ceramic brackets are made of polycrystalline and mono-crystalline ceramic. Ceramics are primarily bounded together by ionic and covalent bonds. Due to this atomic structure, when stress is applied at a certain level the ceramic crystal lattice will be fractured rather than plastically deformed. The monocrystalline bracket is made from a single crystal of alumina.[30]

Polycrystalline brackets which are made from thousands of fused particles of polycrystalline aluminum oxide contain grain boundaries as a result of the different crystal orientations. These grain boundaries and particle fusion interfaces are sites of imperfections which can act as stress concentration areas that encourage crack propagation and lead to a lower fracture strength than the monocrystalline bracket. The brackets production from a single crystal of aluminum oxide eliminates the imperfections found in the polycrystalline brackets. [22]

Poly-crystalline or Alumina poly-crystalline brackets are made of $Al_2O_3$ fused at high temperatures (about 1950°C). while, mono-crystalline brackets are made of one crystal came from combination of particles of $Al_2O_3$ fused at a greater temperature (2100°C) and cooled gradually, thus allowing control of crystallization.[31]

Moreover, mono-crystalline brackets are used in translucent group whereas poly-crystalline are non-translucent. The mono-crystalline brackets are transparent thanks to structure of a single crystal that infiltrates light passage. While Poly-crystalline brackets are 'not translucent due to of lack of boundaries among crystals and impurities incorporated during manufacturing process, in that way obstructing light passage.[29]

For achieving proper aesthetic appearance, non-translucent brackets have to be similar in color and fluorescence to tooth, while translucent brackets need to have adequate transparency and luminousness so as to permit fluorescence and color of the tooth to pass through the brackets. However, it’s essential to have reasonable stability of color. [32]

Mono-crystalline brackets have more optical transparency, and as found by in-vitro study , mono-crystalline brackets have the optical feature of both ceramic and plastic brackets that are affected by thermal cycling, whereas crystalline configuration of ceramic doesn't impact the color stability [22].

Metal reinforced-ceramic bracket in seeking to improve frictional properties of poly-crystalline ceramic, metal reinforced arch-wire slots have been introduced for providing smoother sliding mechanics and more strength.

Several metals lined poly-crystalline ceramic bracket are presently available with 18-carat golden insertions; which are better than stainless-steel regarding the frictional resistance. [(33)(34)]

Wang et al reported that, while ceramic brackets provide superior aesthetics, concerns are raised with respect to higher risk of enamel surface cracking on debonding; the study did not find any remarkable difference in bond strengths among ceramic and metal orthodontic bracket. Enamel detachment happen only when the base was a chemically coated in ceramic bracket and therefore greater bond strengths. Some ceramic orthodontic brackets have a silane coupler as a chemical agent between the base and adhesive material.[(35)]

Many orthodontists are still less willing to accept ceramic brackets due to their undesirable clinical feature. in response to this, manufacturers have struggled over recent years to address many of the clinician concerns. product design and clinical efficiency effectiveness of ceramic brackets has big improvement. Adjustment of the arch wire slot, improvement in bracket base design and refined manufacturing processes have, to a certain extent, tackled some of the problems of friction, strength and control of force associated with ceramic brackets. [(36)]

Some of the negative clinical properties and undesirable features of ceramic brackets that had been presented in the past do not necessarily correspond to the new versions and brands of ceramic orthodontic brackets that exist currently in the market. Also, the marketing of some of the reviewed brackets has been stopped and other advanced versions have been introduced. The new designs of ceramic brackets are distinguished by perfect optical properties in addition to esthetic appearance which not affect their function. Ceramic brackets are durable, allow appropriate force control along treatment periods, and their probability of discoloration is negligible .[(37)]

The introduction of ceramic brackets was considered as pioneering development in the orthodontic therapy of adult patients. Their approval by these patients has been as a revolution in the practice of orthodontics and significantly take part in the propagation and progression of modern orthodontic therapeutic manners.[(37, 38)]

There is a suggestion to recycle ceramic orthodontic brackets. When we compare between deboned ceramic brackets bases and those recycled brackets after heating and application of the silane coupling agent we find that the "recycling" method is efficient in giving a clean surface. Recycled brackets show proper bond strength clinically, but it was markedly less than that of new brackets. During debonding this weaker bond strength of the recycled brackets diminishes the amount of unfavorable enamel removal.[(39)]

**Color Science:**

Aesthetic demands in both orthodontics and dentistry require knowledge of the scientific principles of color.[(40)]

Color can be described according to the Munsell color space in terms of hue, value, and chroma. Hue denotes the name of the color and is determined by the wave length make-up of a color stimulus. Chroma denotes the relative whiteness orblackness of a color.[(41)]

Feller et al described as early as 1961 the color as a three-dimensional entity [(42)]. Color, in other words, is the light modified by an object as perceived by an eye,this light represents a very small portion of the electromagnetic spectrum, the radiant energy of which travels through the space in the form of waves with different wave lengths.[(43)]

Color is not a physical property of an object but rather the capacity of theobject to modify the incident light. As such, color is influenced by the characteristics of the light source and the degree of absorption, transmittance and reflection of the object. When an incident light strikes a surface, spectralabsorption, reflection and transmission are obtained. Opaque bodies absorb andreflect light, while translucent structures absorb and transmit light.[(44)]

**Color stability and Staining of esthetic brackets:**

**1. Factors Affecting:**

Color stability is an important parameter for modem esthetic brackets [(45)]. Color stability of brackets is due to endogenous and exogenous factors. The reason for endogenous discoloration can be found in (U.V.) ultraviolet irradiation and thermal energy. (U.V.) can induce physicochemical reactions in polymer, causing irreversible color changes of the brackets.[(9)] Exogenous effects are foods that can cause staining and even colored mouth rinses [(46)].

The advantages and drawbacks of poly-carbonate brackets and ceramic bracket have been examined in-vitro, particularly changes in the optical characteristics because of discoloration and staining by stains in drinks and foods [(47)]. Optical characteristics like color stability of esthetic brackets have implications for long-standing color matching with underlying teeth [(48)].

Considering the color stability of ceramic brackets, it has been reported that mono-crystalline and poly-crystalline ceramic brackets resist discoloration or staining from any chemical substance likely to be encountered in the mouth [(22)]. However, ceramic orthodontic brackets in the oral environment can be affected by color pigments in coffee,tea,soft drink, and wine. [(49)]

Staining is generally described as being either extrinsic or intrinsic. Intrinsic stain refers to the discoloration that is inside or built into the material, therefore should not apply to machine produced aesthetic brackets. Extrinsic stain refers to discoloration that occurs directly on the surface and is the critical type of stain with respect to dental materials.[(50)]

Food stains and colored mouth washings can produce external discoloration. The material, such as, polymeric structure or filler content, and surface coarseness have a crucial role in the extent of discoloration initiated by diverse materials [(51)]. The degree of color changing is affected by many factors such as, oral hygiene, incomplete polymerization, and water sorption.[(52)]

Environmental effects including temperature, acids, alkalis, enzymes ,oxygen, abrasion, and radiation are reported to chemically impact the color stability of brackets [(53)]. Although mono-crystalline and poly-crystalline ceramic brackets resist staining or discoloration caused by any chemical material in oral cavity, the color pigments in wine, coffee and tea can affect the brackets in the oral environment. [(22)]

An illusion of bracket stain may also occur if there is staining of the adhesive, bonding agent, or tooth. In these instances, the stain is seen through the transparent brackets, although the brackets color themselves have not changed.[29]

A recent study showed that color stability of ceramic brackets is affected in the oral environment. According to this study, plastic and ceramic brackets, when placed in distilled $H_2O$ and subjected to thermal cycling, demonstrated definitive changes upon the analysis of their optical properties. The crystal structure for ceramic orthodontic brackets didn't influence color stability. The authors also suggested that the color stability of aesthetic brackets should be deliberated for their long-term wearing.[19]

Internal discoloration can happen due to ultraviolet irradiation U.V. and thermal energy. U.V. can prompt physicochemical reactions in the bracket polymer that cause irreversible color alterations in ceramic brackets.[52]

- **Considerations after bonding of ceramic brackets:**

Once bounded, brackets make mouth cleaning more problematic. It may act as a retention site for formation of foods and microbial film, elevating risk of enamel de-mineralization and periodontal difficulties.[54]

Mechanical removal of plaque by a tooth brush is best well-known and available and effective technique for avoidance and control of those problems. Also, plaque removing materials should be a part of the patient training as they have important role in teaching and encouraging orthodontic persons to tooth brushing, and among the available plaque removing washers, basic fuchsine and Replak are mostly used in this purpose.[55]

Tooth-brushing snot only as mechanical fulfillment of a mere cosmetic ritual, but also it must make sufficient the bacterial biofilm disturbance. So, patients must understand this massage, to be motivated throughout course of orthodontic management, as a not an easy task. Good communication between patients, family, dentists must happen for reducing incidence of white lesions in persons who wear fixed appliances.[56]

Researches on color changes due to well-known causes of staining such as tea, coffee, Coca Cola, , to poly-carbonate and ceramic brackets have been carried out [57]. Discoloration of esthetic braces by plaque disclosing solutions, acids, oxygen, abrasion, enzymes, and radiation can all reason for chemical break down of esthetic brackets[53].

## 2. Color change measurements:

The analysis of color is defined by Commission Internationale de 1'E′ clairage (C. I. E., 1976) Lab color space. In this 3dimensional color space, with 3 axes being L *, a* and b*, L* indicates lightness, with values range from 0 for perfect black to 100 for pure white. a * refers to chromaticity co-ordinates in red to green axis. +ve a * indicates red color range, while -ve values designates green color range. b* corresponds to chromaticity co-ordinate yellow to blue axis. +ve b * value designates a yellow color range, whereas -ve value designates blue color range. Total color change is evaluated in ΔE a and is estimated via the equation : $\Delta E^* = (\Delta L^{*2} + \Delta A^{*2} + \Delta B^{*2})^{1/2}$ .[58]

The proposed clinical perceptible limit for color equivalent with human eye is 3.7 ΔE a unit. However, it cannot be considered as an "absolute-value", with different light conditions having an effect on color awareness and a light source that come close to standard day light being ideal for color investigation.[58]

Two general approaches can be applied for color analysis of an object; visual and instrumental. A visualcolor estimation is based on visual comparisons of an object with standard color. This technique is most frequently applied in dentistry.

### a. Visual method:

Visual analysis is the oldest method. It is also one of the simplest methods to be used in a clinical setting [59]. Researchers found in the past have reported conflicting results on the agreement between visual shade selection and color measuring devices such as spectrophotometers and colorimeters, authors claiming it to be less accurate.[60]

Visual color assessments are a result of physiological and psychological responses to radiant energy stimulation. Alteration in perception can occur as a result of uncontrolled factors, such as aging, emotions, fatigue, lighting conditions, andmetamerism.[61]

The accuracy of color perception depends on the area of the retinal field stimulated by light. In high illumination, the pupil narrows and when light is dim, the pupil widens, stimulating sensors that are less accurate. As a regulator of pupil diameter, light intensity is a critical factor in color perception and shade matching. Three important features that reflect color matching are successive contrast, simultaneous contrast and color constancy.[62]

Successive contrast is the projection-negative effect that occurs after staring at a colored object. Simultaneous contrast is an instantaneous change in chromatic sensitivity, characterized by a change in appearance due to the surrounding colors. 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 [62]. Different lighting conditions can have an effect on color perception. At low light levels, the rods in the human eye are more dominant and color discrimination is diminished. When the brightness increases, color perception increases. [63]

The quality of light source is the most influential factor. 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 also changes. In that case, a different color is perceived. For example, incandescent light emits light of red wavelengths and can make objects appear to be more red. 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[64]. Objects may appear color matched under one set of lightning conditions and different under another. This experience is called metamerism and speaks to importance of using a standardized light source during shade analysis.[40]

**b. instrumental method:**

- **Spectrophotometers.**

Spectrophotometry is a precise technique that aims to specify a color by taking accurate measurements expressed either quantitatively or graphically. Spectrophotometer operates by passing a beam of light through a sample and measuring the intensity of light reaching a detector[(44)] . Spectrophotometers applied to both in vitro and in vivo environments, make it possible to study the numerous parameters related to color stability [(65)].They estimated light energy quantity reflected from an object at 1–25 nanometer intervals along visible spectrum.[(66)]

Paul et al, tested to what extent spectro-photometric assessment is comparable with human visual determination on 30 persons, three operators with unreported visual color deficiency, independently selected the best match to the middle third of unrestored maxillary central incisor, using a vita classical shade guide, the same teeth were determined by means of a reflectance spectro-photometer three time. All three visual human shade selections matched in only 26 percent, while spectrophotometric shade selections matched in 83 percent. The researchers concluded that spectrophotometric shade analysis is more accurate and more reproducible compared with human shade assessment. [(67)]

Karamouzos et al evaluated the precision of a reflectance spectro-photometer during the longitudinal evaluation of tooth color in vivo. The color of 5 standardized circular areas on the labial surfaces of 6 teeth (4 uppers and 2 lowers), from 22 dental scholars were recorded with a spectro-photometer on three separate days (first, third and thirtieth) by two different examiners. Total color differences (Delta E) were calculated. It was found that all measured teeth areas, recorded by the same examiner, demonstrated minor color changes during the three-time intervals, but was not statistically significant. Regarding inter-examiner reproducibility, the mesial and distal areas of all assessed. teeth presented the most color differences but also not statistically significant. Hence it was concluded by the researchers that the spectrophotometer tested in that study can offer a precise measurement of tooth color in vivo. [(68)]

Hassel et al evaluated the intraexaminer reliability of a clinical spectro-photometer in the measurement of tooth color. three examiners determined L* (lightness), C*(chroma), and H* (hue) value and tooth color twice for 161 anterior teeth of 19 subjects by use of a spectrophotometer. The reliability of the measurements and the total color difference were calculated. Results showed that the intraexaminer reliability was usually acceptable, although a clinically relevant difference between two measurements of an examiner was occasionally detected.[(69)]

Spectrophotometers were compared with observations by human vision or traditional methods; it was found that spectro-photometers offered a 33 % increas in precision and a more objective match in 93.0 % of cases.[(70)]

- **Colorimeters**

The colorimeter is a relatively simple and low-cost device and it is designed to measure color on the basis of three axes or stimuli by using a filter that simulates human eye.[(71)] The disadvantages of using a colorimeter for measuring tooth color include that the instrument is designed to measure flat surfaces, and small aperture colorimeter is prone to significant edge-loss effects.[(72)]

In particular, tri stimulus colorimeters are capable of detecting color differences below visual perception threshold [(67)]. Human perception of color is a very complex process which encompasses both subjective and objective phenomena. The perceptual factor of the color match may be as subjective as "hot" or "cold" to a particular individual in a particular setting. Therefore, color evaluation by visual comparisons may not be a reliable method due to inconsistencies inherent in color perception and specification among observers.[(73)]

Hence, preceding any practical application of technology that quantifies color differences, parameters that have visual significance must first be established.[(74)]

Colorimeters measure tristimulus values and filter light in red, green and blue areas of the visible spectrum. Colorimeters are not registering spectral reflectance and can be less accurate than spectrophotometers.[(75)]

- **Digital cameras and imaging systems.**

Modern photography and computer science led to wide-spread applying of digital cameras for colored imaging that can be evaluated with photography software facilitating collection of quantitative color parameters from all parts of such images. digital cameras analysis is a m0re cost-effective and simpler method than conventional color assessment machines such as colorimeters or spectrophotometers.[(76)]

Digital photograph analysis gives similar results obtained by spectrophotometer, but the using of digital photograph analysis is more worth in assessment of color changes because of its easiness of application.[(77)]

Furthermore, a very high correlation was found to exist between spectro-photometer and digital-camera for all of the Commission Internationaledel'Eclairage ( C.I.E., 2004 ) L*, a*, and b* color coordinates [(78)]. Thus, when combined with appropriate calibration protocols, digital photography, show potential to be utilized in color assessment for dentistry [(79)].

The utilizing of computer programs for image processing to monitor changes in brightness was examined by Bentley et al, [(80)] who established that software analysis of pictures with internal color controls offers an index of brightness, which is reproducible from photo to photo. Photographs using an image analysis system adapted for whiteness assessments have been examined by Lath et al [(81)] The two authors concluded that the adapted digital image analysis soft wares could offer an alternative technique for whiteness assessment.

Also, digital cameras obtain Red, Green and Blue image information that is used to produce a color picture. (R.G.B) color model is other model in which the three lights are added together in various techniques to reproduce a broad display of light colors [(82)]. Many methods are used to translate this data into valuable colored data [(83)].

## Conclusion

The clinical use of spectrophotometers and camera digital to determine the color stability of aesthetic orthodontic brackets is the best choice. The ceramic bracket is better than any other aesthetic brackets in color stability property.

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