Digital Analysis of Staining Properties of Clear Aesthetic Brackets

by

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Abstract

DIGITAL ANALYSIS OF STAINING PROPERTIES OF CLEAR AESTHETIC BRACKETS

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AIM: To analyze staining properties of aesthetic brackets.

MATERIAL & METHODS: A total of 400 tooth-coloured brackets from 10 brands (5 ceramic and 5 plastic) were investigated. Cumulative effects of staining agents were analyzed at simulated light and heavy consumption levels. Study groups were immersed in the staining agents consecutively at 37°C. The control group was exposed to artificial saliva. Samples were analyzed digitally to obtain the L^*, a^*, and b^* (lightness, red-green, and yellow-blue) colour readings. Using these values total colour change (ΔE^*) was also calculated. A general linear model (ANOVA) test was used for statistical comparisons.

RESULTS: Significant differences were observed in L^*, and b^* values of ceramic brackets at all consumption levels ($p \leq .0001$). All values had significant differences amongst the plastic brackets ($p \leq .0001$), except for L^* with heavy exposure. Total ΔE^* values for ceramic and plastic brackets were 11 and 26, respectively.

CONCLUSIONS: Both plastic and ceramic brackets showed changes in colour when exposed to staining agents, with plastic brackets being the most affected.

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Chapter I

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Introduction

Aesthetics have long been a focus in dentistry, and particularly in orthodontics. The demand for improved aesthetic appliances has therefore increased. Today there are many different brackets made of various aesthetic materials to help satisfy this demand. The mechanical features of these brackets have been the subject of extensive research, but their aesthetic qualities have been analyzed in only a small number of studies (Lee 2008, Faltermeier, Behr and Müssig 2007, Eliades, Johnston and Eliades 1995). The aesthetics of the brackets are not only critical on the day of bonding, but their aesthetic longevity depends on their ability to endure the hardship of the oral environment, including exposure to foods and various chemicals with a propensity to stain.

The choice of using aesthetic brackets in daily orthodontic practice presents the clinician with many compromises, including; their tendency to deform under pressure, increase in size, wear of opposing teeth, friction, fracture, and difficulty during debonding and increased cost (Birnie 1990, Russell 2005). These compromises are accepted to allow for the benefit of improved appearance during treatment and thus it is critical to know how staining agents/food and oral environment would affect their optical properties.

Chapter II

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Literature Review

A recent increase has been reported in the number of adult patients who are seeking orthodontic treatment (Khan and Horrocks 1991). Accordingly, there is a demand for better and more aesthetically pleasing treatment options (Birnie 1990). There is a wide variation in the clear (aesthetic) brackets available in orthodontics. The optical properties of these materials in terms of colour stability, and distortion of the slot dimension (Alkire, Bagby, Gladwin et al 2007, Nishio, Mendes, Almeida et al 2009) as well as reported fragility continue to be areas of interest for the clinician.

The first clear brackets were plastic and composed of polycarbonate and plastic moulding powder (Dobrin, Kamel and Musich 1975). These brackets did not have adequate resistance to discoloration and were highly fragile under heavy occlusal and orthodontic forces. (De Pulido and Powers 1983). There have been many developments in the fabrication of plastic bracket since their introduction to daily orthodontic practice. Today's choice for clear bracket material is ceramic rather than plastic. Ceramic brackets have the advantage of having superior mechanical qualities in terms of hardness and stiffness. Moreover ceramic brackets are reported to provide excellent colour fidelity and stain resistance (Sinha and Nanda 1997). However, it is recognized that their hardness can lead to abrasion of occluding enamel (Douglass 1989). These brackets are also quite brittle and this predisposes them to crack when stressed, leading to failure (Eliades 2007).

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 (Anusavice 2003). Alumina (Al_2O_3) is a typical example of modern ceramics, others include zirconia (ZnO_2) and combinations of both materials (Russell 2005, Jena, Duggal, and Mehrotra 2007). Both monocrystalline and polycrystalline alumina are used to manufacture orthodontic ceramic brackets (Jena, Duggal, and Mehrotra 2007), but they present some problems due to their brittle nature. The single-crystal ceramics are the most transparent and consequently make the most aesthetically pleasing appliances. Single crystal brackets are noticeably clearer than polycrystalline brackets and therefore have greater translucence (Jena, Duggal, and Mehrotra 2007). The most apparent difference between polycrystalline and single crystal brackets is in their optical clarity. The critical stress to induce a crack depends on the modulus and critical surface tension of the material. Aging conditions of the intraoral environment predisposes brackets to fracture by lowering the critical surface tension of the material and thereby reducing the critical stress value. Alumina ceramics are known to have reduced three-point bending strength after exposure to water (Zinelis, Eliades, Eliades et al. 2005).

In a general comparison, ceramic brackets have; superior mechanical properties, increased transparency, decreased reactivity with the oral environment, and a more inert biological character. The inert biological character is a matter of dispute for plastic brackets because of the potential action of various polymers in the plastic (Eliades 2007). The disadvantages associated with plastic brackets include their decreased mechanical properties compared with ceramic brackets and their inability to withstand the internal forces generated by rectangular wires (Arici and Regan 1997). In addition, water sorption of plastic brackets could cause a plasticizing effect which decreases the properties of the polymeric structure in a wet environment such as the oral cavity (Krauss 2010).

Environmental effects including heat, acids, alkalis, oxygen, abrasion, enzymes and radiation are reported to chemically affect the colour stability of clear brackets (Kusy and Whitley 2005). Although monocrystalline and polycrystalline ceramic brackets resist staining or discoloration resulting from any chemical substance to be encountered in the mouth (Swartz 1988), the colour pigments in wine, coffee and tea (Bishara and Fehr 1997) can affect the brackets in the oral environment. 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 themselves have not changed colour. (Jena, Duggal, and Mehrotra 2007).

Aesthetic demands in both dentistry and orthodontics require knowledge of the scientific principles of colour. Light is electromagnetic radiation that is able to be detected by the human eye. Humans are able to perceive light in a range of wavelengths from approximately 400nm, seen as violet, to 700nm, appearing as dark red. For an object to be visual, it must transmit or reflect light directed at it from an external source. The incident light is usually composed of a mixture of varying wavelengths, referred to as polychromatic and is selectively absorbed or scattered. Incident light resembles reflected or transmitted light in spectral distribution, however certain of its wavelengths can be altered in size (Anusavice 2003). In order to precisely describe the colour of an object three distinct variables have to be measured these include hue, value and chroma. Hue describes the dominant colour of an object, more specifically the prevailing wavelength of its spectral distribution, for example, red, yellow or blue. Value indicates the lightness of a colour ranging from pure black to pure white. Chroma is the degree of colour saturation and describes the strength, intensity or vividness of a colour. In dentistry value identifies the lightness or darkness of a colour and is independent of the hue. (Anusavice 2003)

The Commission Internationale de l'Éclairage (CIE), an organisation devoted to standardisation in areas such as colour and appearance, defined in 1931 a standard light source, to represent how the human visual system responds to a given colour. In 1976, the CIE further defined a colour space, CIE Lab, that supports the accepted theory of colour perception based on three separate colour receptors (red, green and blue) in the eye and is currently one of the most popular systems of colour analysis. The CIE Lab colour space represents a uniform colour space, in which equal distances correspond to equal perceived colour differences. In this three-dimensional colour space with the three axes are L^*, a^* and b^*, the L* refers to the lightness. Its value ranges from 0 for perfect black to 100 for perfect white. The a^* refers to the chromaticity coordinates in the red–green axis. Positive a^* values reflect the red colour range and negative values indicate green colour range. The b^* corresponds to the chromaticity coordinate yellow–blue axis. Positive b^* values indicate yellow colour range while negative values indicate the blue colour range. Colour change is measured in terms of ΔE and measured by the equation:

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

(McLaren 1987)

Staining is generally described as being either extrinsic or intrinsic. Intrinsic stain or imbibition of colorant, refers to discolouration that is inside or built into the material, therefore should not apply to machine produced aesthetic brackets. Extrinsic stain refers to discolouration that occurs directly on the surface and is the critical type of stain with respect to dental materials (Watts and Addy 2001). It has been reported that the mechanisms contributing to the formation of extrinsic stains are the production of coloured components in plaque by chromogenic bacteria, also the retention of coloured substances from dietary constituents passing through the oral cavity and the formation of coloured products from the chemical transformation of pellicle components (Eriksen and Nordbö 1978).

A recent study showed that the colour stability of ceramic brackets is affected in the oral environment (Lee 2008). According to this paper, 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. Crystal structure for the ceramic brackets did not influence colour stability. The authors also suggested that colour stability of aesthetic brackets should be considered for their long-term use.

Another interesting study concluded that the consumption of certain food has a direct effect on the degree of colour changes in clear brackets (Faltermeier, Behr and Müssig 2007). Faltermeier, Behr and Müssig 2007, plastic brackets were exposed to red wine, coffee, tea, and UV light and it was found that each of these substances caused undesirable optical changes in the brackets.

Staining of the adhesives used to bond the brackets to the tooth is another factor that must be considered, when evaluating the aesthetics of orthodontic appliances. The major current category of orthodontic adhesives is dental composite resins. These composite resins consist of two components an organic matrix and a powdered ceramic, such as barium aluminoborate silica glass. The organic matrix usually consists of Bis-GMA (2,2-bis[4-(2-hydroxy-3-methacryloxypropoxy)phenyl]propane) or UDMA (1,6-bis(methacryloxy-2-ethoxycarbonylamino)-2,4,4-trimethylhexan), with varying amounts of compomers such as TEGDMA (Triethylene glycol dimethacrylate) to increase viscosity (Brantley and Eliades 2001). Cörekçi, Irgın, and Malkoç et al. 2010, exposed 6 different orthodontic adhesive resins, consisting of various compositions of Bis-GMA, UDMA and TEGDMA, to staining solution. They found all resins exhibited colour change over the visually perceptible threshold, with range of ΔE values from 24.58-46.74. Furthermore, Joo, Lee and Lee et al. 2011, was able to show that orthodontic bonding agents (largely comprised of TEGMA (Brantley and Eliades 2001) showed clinically perceptible stains. They found, following debonding and removal of excess adhesive that there were ΔE values ranging from 6.6-17.6 in the bonding agent left as tags in the enamel. It is apparent from these studies that adhesives used in orthodontic bonding may have a negative impact of the appearance of aesthetic brackets, whether or the not the brackets themselves have experienced colour change.

The interest in colour changes and colour matching in dentistry has increased over the past few decades. The investigation of colour changes can involve as little as one, or a combination of three tools. These include spectrophotometers, colorimeters, and digital photography analysis (Chu, Trushkowsky and Paravina 2010). Spectrophotometers are described as the most accurate and flexible instruments used for colour matching in dentistry (Paul, Pete, Rodoni et al 2004). They quantify the amounted of reflected light energy by an object at 1-25nm intervals in the visible light spectrum. The light obtained by the spectrophotometer is converted in to a useable signal, and then translated into a useful form for clinicians (Kielbassa, Beheim-Schwarzbach, Neumann et al. 2009). These measurements are frequently used in the fabrication of dental shade guides. (Lagouvardos, Fougia, Diamantopoulou et al. 2009). Colorimeters have a different mechanism of action. They filter the colour of the object into three colours of the visible spectrum red, green and blue. These measurements recorded with a colorimeter are therefore referred to as tristimulus values (Chu, Trushkowsky and Paravina 2010). A third option for evaluation of colour is the analysis of the images acquired through digital photography. The majority of digital cameras acquire images based on the combination of red, green and blue light known as the RGB colour model. Once the image is attained, a computer program is used to analyze the optical properties of selected areas of interest (Chu, Trushkowsky and Paravina 2010). The uses of spectrophotometers and colorimeters have been shown to be valuable in colour matching in dentistry at a level superior to the human eye (Tung, Goldstein, Jang et al. 2002). The use of either the spectrophotometer or the colorimeter requires the purchase of the equipment; hence the analysis of digital photos may represent a more practical approach to evaluating colour in dentistry. Recently Cal, Güneri and Kose 2006, reported that the analysis of digital photographs yielded statistically similar results to spectrophotometers, when evaluating dental colour shade guides. In this study the researchers analyzed sixty shade tabs from three shade guides and subjected them to evaluation using spectrophotometers and the analysis of digital images. The results of this study indicated no differences when determining the colour composition of the various shade tabs using either method. There was however disagreement in the evaluation of the lightness of the shade guides. This lack of continuity was speculated to be a result of differences in the required lighting conditions needed by the two techniques. These promising results indicate that the use of digital photography is worthwhile in the evaluation of colour changes due to the ease of application.

Analysis of colour in dentistry can also be made with the human eye, although the use technology has lead to more consistent results (Tung, Goldstein, Jang et al. 2002). Colour is perceived 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 cones can adjust the variation of light intensity. The area around the fovea centralis has a mixture of sensors responsible for differences in colour discrimination among observers with normal colour vision (Chu 2002). The accuracy of colour 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 colour perception and shade matching. Three important features that reflect colour matching are successive contrast, simultaneous contrast and colour constancy (Brewer, Wee, and Seghi 2004). Successive contrast is the projection-negative effect that occurs after staring at a coloured object. Simultaneous contrast is an instantaneous change in chromatic sensitivity, characterized by a change in appearance due to the surrounding colours. Colour constancy occurs because we perceive certain objects as being of different colour and the object seems to be of the same colour even if the light received by the eye varies (Brewer, Wee, and Seghi 2004). Different lighting conditions can have an effect on colour perception. At low light levels, the rods in the human eye are more dominant and colour discrimination is diminished. When the brightness increases colour perception increases (Anusavice 2003). The quality of light source is the most influential factor in determining shade. The ideal light source is natural light, occurring around mid-day for accurate colour comparison. The time of the day, month and weather conditions affect the colour of sunlight. If the light source changes, then the light reflected from an object also changes. In that case, a different colour 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 colour matching. The light source that approximates standard daylight is ideal for shade matching (Chu 2002). Objects may appear colour 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 (Anusavice 2003). The perceptible limit for the human eye of reflected colour changes in aesthetic dentistry, a colour difference value of greater than 2 ΔE units (Wozniak 1987) and the proposed clinical perceptible limit for colour matching were 3.7 ΔE units (Johnston and Kao 1989, Fruits, Duncanson, and Miranda, 1997).

To date no study has investigated the cumulative effects of staining agents on the colour stability of clear brackets. Moreover, the long terms effects of staining agents based on their level of consumption has not been reported. Although the kind of material and crystal structure for ceramic brackets did not influence colour stability, and colour stability was mainly brand-dependent in a previous study by Lee 2008, colour stability of aesthetic brackets needs to be evaluated for their long-term use.

All of the previous studies investigating at the optical properties of aesthetic brackets have utilized a spectrophotometer to analyze their results. In the present study we utilized a digital analysis method that is proposed by Cal, Güneri and Kose 2006.

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Purpose

The purpose of this study was to determine the long-term cumulative effects of certain spices, beverages and artificial saliva, based on their exposure time, to the colour stability of both plastic and ceramic brackets using a digital analysis.

Hypothesis

Both ceramic and plastic brackets will have their optical properties altered according to increased consumption of various staining agents.

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Materials and Method

This study was conducted using 10 different types of clear brackets from popular brands to form both the ceramic (5 brands), and the plastic groups (5 brands) located in Table 1. It should be noted that Spirit MB although considered a plastic bracket for the present study, is more accurately described as a hybrid bracket as it is composed of polycarbonate reinforced with ceramic. The cumulative discolouration by staining agents on the brackets was determined by using two estimated consumption levels in terms of exposure time: mild and heavy. The staining agents used were selected after careful evaluation of the results from a pilot experiment (Rykiss, Akyalcin, Wiltshire et al. 2010). It was the aim of this pilot study to determine the type of staining agents that would result in the greatest amount of discolouration on clear brackets.

In the pilot study the staining properties of six spices/beverages were tested products were tested: black tea (Tim Hortons, Ont, Canada), tomato juice (Heinz Tomato Juice. H.J. Heinz Company of Canada, ON, Canada), red wine (Billygoat Hill Shiraz. Harvey River Bridge Estate, WA, USA), curry paste (Patak's Madras Curry Paste, National Importers, B.C., Canada), black coffee (Tim Hortons, ON, Canada) and cola (Coca-Cola Classic, The Coca-Cola Company, GA, USA). A total of 70 brackets (10 from each brand), were divided into 7 groups, which included 1 control and 6 experimental groups. Each testing solution was comprised of 50ml of the product. The control brackets were photographed digitally to obtain the baseline *L*, *a*, *b* values, then 10 brackets (one of each brand) were immersed in test solutions for one week and the post-treatment images of the test materials were acquired. All L, a, b values were analyzed by

Adobe Photoshop CS5 graphic software (Adobe Systems Inc. CA, USA), and comparisons were observed between the control and test brackets. The table 2 shows the *L*, *a*, and *b* values from all the different groups. Multiple comparisons with Mann-Whitney test indicated that in comparison to the control group the brackets treated with red wine had the most significant staining characteristics ($p<0.05$ for all L^*, a^* and b^* values) followed by tea ($p<0.05$ for a^*, b^*) and curry ($p<0.05$ for b^*) on the aesthetic brackets. Based on the preliminary results red wine, tea, and curry paste were included in the current study. Coffee did not significantly affect the colour profile. However, it was the fourth highest staining agent based on the preliminary test that was confirmed by a study by Faltermeier el al. (2007). Therefore, it was also included in the main study.

The final products that were included in the study were: black tea (Tim Hortons, ON, Canada), regular black coffee (Tim Hortons. ON, Canada), curry paste (Patak's Madras Curry Paste, National Importers, B.C., Canada) and red wine (Billygoat Hill Shiraz. Harvey River Bridge Estate, WA, USA).

Estimated consumption for each substance was based on a 10-minute exposure to the substance at each use. Although orthodontic treatment, on the average, may last up to two-years the total evaluation time for the experiment was based on a 6-month (26 week) consumption period since that would allow adequate time changes, if any, to occur. These exposure times were speculated from personal opinion and observation. Consumption scenarios and the total hours of testing for each consumption level were calculated and are presented in Table 3. The calculation to determine the number of hours required for each staining solution was as following equation:

Hours = (# of exposures/week x 26weeks x 10minutes/exposure) / 60minutes/hour

Two groups were formed for both the plastic and ceramic brackets: a control group and a study group. In the study group, 10 brackets of each type were immersed in 50 ml of the various staining solutions and were then placed in an oscillating hot water bath (Precision Dubnoff Reciprocal Shaking Bath, Mandel Scientific Inc. ON, Canada) at a temperature of 37°C. for the amounts of time noted in Table 3. All of the brackets were then rinsed together, using a standard ultrasound bath (LR606, L&R, NJ, USA), in 50ml of de-ionized water at 37°C for 1 minute, before being immersed in the next solution. Simulated tooth brushing was avoided for standardization issues and also to preserve the surface texture of plastic brackets.

Control groups of 10 brackets of each type were stored in synthetic saliva, with a composition of Methyl-p-hydroxybenzoate, 2.00; sodium carboxymethyl cellulose, 10.0; KCl, 0.625; $MgCl_2.6H_2O$, 0.059; $CaCl_2.2H_2O$, 0.166; K_2HPO_4, 0.804; K_2HPO_4, 0.326 (units g/L) (McKnight-Hanes and Whitford 1992), also placed in the oscillating hot water bath at 37°C, for the corresponding amount of time in each study group. This group would represent the outcome in brackets exposed to a simulated oral environment but not to spices or beverages. Those brackets are still subjected to changes in colour due to the natural humid environment in the mouth as evidenced by Lee 2008. Colour readings were made on 10 new brackets from each brand to determine the marketed colour profile of virgin unexposed brackets.

The colour reading protocol was based on the digital method proposed by Cal, Güneri and Kose, 2007. Digital images of brackets were taken against a black cardboard surface at the beginning of the study, and again after either saliva or staining food exposure. No adhesive was used when placing the brackets onto the cardboard to ensure that only the optical properties of the brackets were analyzed. A white standard photograph paper was also placed alongside the brackets as a calibration tool in order to eliminate the environmental factors. A digital camera (D90, Nikon, Tokyo, Japan) was fixed on a tripod, with 40-cm. object–camera distance oriented perpendicular to the test samples to acquire the digital image. The image was illuminated using a 6500K fluorescent light bulb (General Electric, ON, Canada), which emits the equivalent light spectrum of natural light. This image was saved in TIFF format, and was later analyzed by commercially available graphic software (Adobe Photoshop CS4, Adobe Systems Inc., San Jose, CA, USA). Fixed square areas that were 20 x 20 pixels in dimension were cropped from both the mesial and distal wings of each specimen. The L^*, a^*, b^* values of these areas were measured twice by using the histogram function of the software, and the mean values were used for each specimen. The experimental values were divided by the L^*, a^*, b^* values of the adjacent white photograph paper in order to eliminate the potential effects of the environmental factors, and the 'corrected' L^*, a^*, b^* values of each specimen were recorded. The colour change (ΔE) using uncorrected L^*, a^*, b^* values for each subgroup and each consumption level were calculated using:

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

Statistical Analysis

To determine the significance of changes in colour parameters *L**, *a** and *b**, each bracket subgroup at each consumption level, a general linear model, Analysis of Variance (ANOVA) was used to compare the means between intra-group comparisons (study-control) and intergroup comparisons (ceramic-plastic) at light and heavy consumption exposures. Also an ANOVA was carried out for an intra-group comparison of differences, study minus controls, (phase 1-phase 2) and intergroup comparison of differences, study minus controls, (ceramic-plastic). Statistical significance was set at $p<0.05$ for all tests.

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Results

The colour measurements for the ceramic and plastic brackets groups are presented in Table 4. The mean and standard deviations of the corrected *L**, *a**, and *b** values are given for the study and control groups at each exposure level. Phase 0 refers to the marketed baseline colour profile, phase 1, and phase 2 refers to the colour profiles that correspond to mild and heavy consumption groups respectively. The *L** values for the plastic groups decreased from phase 0 to phase 2 for both the study and control groups. The *L** values slightly increased from phase 0 to phase 2 in the ceramic control groups and decreased over the same period in the ceramic study groups. The range of *L** values was 0.40 for the plastic study group of light exposure to 0.65 for the unexposed plastic group. The *a** showed very small changes in all groups of both ceramic and plastic groups, values varied from 0.98 for both the plastic light and heavy exposure control groups to 1.00 in the plastic heavy exposure study group. The *b** values exhibited small increases from phase 0 to phase 2 in plastic and ceramic control groups and small increases from phase 0 to phase 1 in the study groups. The range of *b** values ranged in the ceramic group from 0.99 in the control phase 0 group to 1.03 by the phase 1 study group. The range of *b** values for plastic brackets was 1.01 in the phase 1 control group to 1.04 shared by phase 1 and 2 study groups. The range of standard deviations in *L** values was 0.05 in the unexposed ceramic group to 0.11 in the unexposed plastic group. The standard deviation of all *a** and *b** values for all groups was 0.01-0.02. These values are specific to the digital system used this study and may differ from other readings that are made by a spectrophotometer.

Table 5 shows the intra-group comparisons for the plastic and ceramic groups at each phase. The study groups at each phase are compared to the matching control groups at the given exposure level. The *L** values were significantly lower for the control as compared the study groups for both the plastic and ceramic brackets in phases 1 and 2 ($p \leq .0001$). The intra-group comparisons for *a** values were larger in all study groups and the differences were significant ($p<0.05$), except for the ceramic brackets group in phase 2, which revealed *a** values 0.99 for both study and control groups ($p=0.722$). Intra-group *b** comparisons showed larger values for study groups in all phases for both ceramic and plastic groups and all values were significant ($p \leq 0.001$).

Table 6 represents the inter-group comparisons. Those comparisons provide some information in which variables regarding the plastic and ceramic brackets differed from each other throughout the experiment. In the study groups *L** values were smaller in the plastic than the ceramic brackets at both exposure levels and all differences were significant ($p \leq .0001$). Significant differences were also recorded in comparison of the study groups for *a** values at the mild exposure level ($p=0.001$) and *b** values at both the mild ($p=0.0039$) and heavy ($p=0.0058$) exposure levels. For all *a** and *b** values, in the study groups, the plastic groups were greater than or equal to the ceramic groups. The comparison of control groups revealed significantly larger *L** values for the ceramic groups at both the mild ($p=0.0236$) and heavy ($p=0.0087$) exposure levels. The *a** values were equal in magnitude for light exposure groups at 0.98 and significantly different between the control groups only at the heavy exposure level ($p \leq .0001$). The *b** values were larger in plastic than ceramic control groups, but only significantly different between the control groups at the heavy exposure level ($p=0.0015$).

The inter-group comparison of differences between the ceramic (study minus control) and plastic (study minus control) at each phase are presented in Table 7. The comparisons of differences of *L** values, showed larger differences for plastic brackets, at -0.15, compared to ceramic brackets at -0.08 and were significant in both phase 1 ($p=0.0026$) and phase 2 ($p=0.011$), The differences for *a** were larger for plastic groups and were also significant in both phases ($p=0.048$ and $p \leq 0.0001$). *b** differences, although higher in the ceramic groups for both phases, were not significant in comparison ($p>0.05$).

Table 8 reveals the intra-group group contrasts: it compares phase 1 (study minus control) to phase 2 (study minus control) for both ceramic and plastic groups. *L** and *b** value differences were equivalent, for phases 1 and 2, in both the plastic and ceramic groups, showing no statistical significance ($p>0.05$). The differences in *a** values for the ceramic group were larger in phase 1 than phase 2 ($p=0.0037$). The plastic group showed no significance for differences in *a** values between phase 1 and 2 ($p>0.05$).

The overall colour change as denoted by ΔE can be found in Tables 9 and 10. Table 9 shows the overall colour changes for plastic and ceramic brackets and Table 10 presents brand-specific colour changes. ΔE I indicates the colour change between phase 0 and phase 1 and ΔE II represents the colour changes between phases 1 and 2. Therefore, the total colour change (ΔE) at the end of the experiment can be calculated by summing up ΔE I and II. Our results indicate that ceramic brackets had less colour change than plastic brackets at the end of phase 1 for both the study and control groups. Although the ΔE II values were much less than ΔE I values, ceramic brackets were affected slightly more than the plastics in this phase. The total Δ*E* values representing the whole experiment showed the largest change for the plastic study group (26) followed by the plastic control group (13). The ceramic groups showed less change as the study group showed a total Δ*E* value of 11 and the control group had a total Δ*E* of 7. The breakdown of colour profile changes (Δ*E*) based on individual brackets types is shown in Table 10. The range of Δ*E* values representing the whole experiment in the study groups ranged from 6, exhibited by Inspire Ice and Innovation-C, to 37 for Silkon Plus and 39 for Vogue. The range of control group Δ*E* values were 0.06, displayed by Radiance and Envision, to 22 by Damon 3 and 23 by Vogue. The range of Δ*E* for phase 1 was 2 for the Inspire Ice to 34 by Silkon Plus. The largest Δ*E* between the end of phase 1 and 2 in the study groups was found for Clarity at 9. The smallest Δ*E* for this period in the study groups was reported for Innovation-C at 2. Among the ceramic brackets the largest total Δ*E* values were observed for Clarity and Radiance brackets at 19 and 21 respectively. When the ceramic brackets are divided into monocrystalline and polycrystalline groups it becomes clear that neither composition ensures stain resistance. The total Δ*E* range for the monocrystalline brackets provide the range for ceramic brackets with Inspire Ice at 6 providing the lowest and Radiance at 21 providing the highest values of the ceramic study groups. The Spirit MB study group was the only plastic bracket to have a total Δ*E* less than a ceramic bracket group, showing a value of 11, which is 15 smaller than any other plastic brackets. All bracket study groups showed larger total Δ*E* values than their control groups, except Spirit MB, which showed equivalent results and Innovation-C whose control group's Δ*E* was 1 larger that its study group.

Chapter VI

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Discussion

Orthodontic treatment aims to provide individuals with an aesthetically pleasing smile. Patients have become increasingly demanding regarding the use of more aesthetically tolerable appliances during treatment (Russell 2005). There are now many options for more aesthetically pleasing orthodontic appliances namely lingual braces and clear aligners, as well as clear braces which are the main focus of this investigation. The mechanical properties of both ceramic and plastic brackets have been investigated at length. The susceptibility of these aesthetic brackets to colour change, when presented with food products and conditions that mimic the oral environment, has not been studied as thoroughly. It was the goal of this research to analyze how certain spices and beverages in the simulated oral environment will affect the optical properties of aesthetic brackets.

According to our results, the hypothesis of this paper was confirmed. However, the results of this paper should be interpreted very carefully. The measurement which accounts for overall colour change is ΔE. First, it should be interpreted that a change in ΔE may not necessarily indicate a clinically significant difference. Based on the studies investigating colour changes by spectrophotometers in aesthetic dentistry the clinically perceptible threshold for this parameter is ΔE=3.7 (Johnston and Kao 1989, Fruits, Duncanson, and Miranda, 1997).

Second, the critical features of colour analysis are translucency and opalescence. Translucency is the property of a substance that permits the passage of light; it can be described as a state between complete opacity and transparency (Powers 2006).

Opalescence refers to a light scattering occurrence found in translucent materials wherein a blue colour is produced due the scattering of short wavelength light (Lee and Yu 2007). It is critical to note that clear brackets are manufactured within various shades of tooth colour incorporating varying degrees of both qualities. Opalescence is clearly demonstrated in Radiance brackets, which appear to have blue-white colour in their freshly marketed state. One may be able to attribute the changes in ΔE to a loss of opalescence which may not necessarily relate to a deterioration in appearance. Opalescence, therefore, could have lead to production of false negatives in the results. However without adequate expertise in the physics of light it impossible to conclude with certainty which of the two processes is occurring. It is important only to realize that many processes can lead to colour change. It is also essential to remember that each brand started off with different colour profiles from one another. This is an important distinction, as the goal of this research was to determine the bracket type which will exhibit the least colour changes. We did not endeavour to determine the most aesthetic brackets, either before or after exposure to stainants. Brackets with lighter shades may therefore exhibit more change, but remain more aesthetic than the darker brackets that exhibited less colour change. No attempt was made to mechanically debride the brackets, before, during or after this study, in order to limit the number of confounding variables. Conversely, one must be aware that mechanical debridement of the brackets may yield alternative results and the influence of brushing on colour change may be worthy of future exploration. Another variable that must be considered when extrapolating these results to clinical performance is the potential of the orthodontic adhesives to become stained. As discussed previously, the orthodontic adhesives and bonding agents currently used contain Bis-GMA, UDMA, and TEGDMA, which have shown a high propensity for discolouration when exposed to stainants expected to be encountered in the oral environment (Cörekçi, Irgın, and Malkoç et al. 2010, Joo, Lee and Lee et al. 2011). Due to the translucency exhibited by ceramic and plastic brackets, staining of the adhesive would have a negative effect on the aesthetic of the brackets, whether or not the brackets had stained themselves. Therefore, the ΔE values reported in this study indicated an overall change in the colour stability however, it must be remembered that the brackets used in this study were subjected to a far more controlled environment than would exist *in vivo*.

Despite the fact that our results demonstrated higher levels of colour change for the plastic brackets in general, it should be kept in mind that many structural differences remain even within the plastic and ceramic bracket groups. In the ceramic group some of the brackets were monocrystalline and others were polycrystalline whereas the plastic groups showed an array of materials namely polycarbonate and polyurethane. Furthermore, many of the brackets especially the plastics, were subjected to further enhancement protocols by the manufacturers in terms of reinforcement with surface treatments and the addition of various fillers. This could explain the positive result exhibited by the Spirit MB brackets. Although constructed of polycarbonate, Spirit MB brackets are reinforced with ceramic. This feature of Spirit MB adds power to the results of our study as the addition of ceramic to a plastic brackets provides added resistance to staining. Each of the brackets are made from different materials which made it rather difficult to study their relationships to each other. Accordingly, it was the aim of this study to determine the trends of the two main types, ceramic and plastic, to gain a consensus on the groups as a whole. As evidenced from our results, brackets from both the ceramic and plastic groups demonstrated alterations in their optical properties even when exposed to artificial saliva. This finding may indicate the differences between the different brands in terms of surface finishing since saliva exposure might have created a washing effect. This effect of artificial is saliva is noted in the study Kurtulmus, Kumbuloglu, Aktas et al 2010, as they found colour change after placing a variety of dental materials in artificial saliva for 7 days, but this effect has also been shown when orthodontic brackets are thermally cycled in distilled water (Lee 2008), indicating that the effect is washing as opposed to staining by the artificial saliva. Furthermore, our results may serve as a reference to the manufacturer to further analyze the surface structure and composition of the individual brands of brackets to determine the cause of their susceptibility or resistance to stain. Perhaps the marketed colour profile of the brackets could be altered realistically to compensate for the changes to be expected due to oral conditions.

Although ΔE indicated the overall colour change, Table 5 details the change in colour profile better. This table shows that study groups were statistically different from the control groups for both plastic and ceramic groups in virtually all CIE (Commission Internationale de l'Eclairage) L^*, a^* and b^* parameters at both consumption levels. It is clear that the brackets are being affected by the food products and that even light consumption of these may lead to perceivable colour alterations.

Our results clearly indicate that, as a group, the ceramic brackets showed less colour change than plastic ones. Their mean ΔE values were 15 and 6 units below the averages of the plastic brackets in the study and control groups respectively. The colour change was more apparent during the initial phase of exposure in each group. However, this may also be affected by the differences in the marketed colour profile. Perhaps a better way to approach how the staining agents affected the colour profile during the first phase, ΔE values of the control group can be subtracted from the ΔE values of the study groups. Control brackets that were placed in saliva had their initial surface characteristics and colour profile affected also as a consequence of being exposed to a neutral substance at ambient mouth temperature. Similarly, Lee 2008 investigated the effect of thermal cycling, in distilled water, on plastic and ceramic brackets. They subjected 4 ceramic and 4 plastic brackets to thermal cycling for 5000 cycles. These cycles included second dwell times at 5º and 55º Celsius, which totalled 20.8 hours. The CIE (Commission Internationale de l'Eclairage) units of the brackets were calculated before and after the thermal cycling with a spectrophotometer and revealed ΔE values that ranged from 1.4-6.4. Only 3 of 8 yielded clinically significant results and neither plastic nor ceramic brackets were deemed to be superior in colour stability. These results contrast the present findings, which demonstrated the superior stain resistance of ceramic brackets and confirm the great variation found among the individual bracket brands. The brackets resistance to stain appears to be more brand dependent than merely a result of their being either ceramic or plastic. The results of Lee 2008 cannot be directly compared to the present study for three main reasons. First, different brackets were tested, and second, the brackets were not exposed to differing heat cycles in the present study. Finally, the brackets in Lee's study were subjected to a shorter experimental period of time. Although these studies are not of identical design, the fact that the results are of a similar nature indicate that colour change should be expected when brackets are exposed to the washing effect of the oral environment.

Our results also indicated that after a certain threshold was reached, the change in colour profile stabilized. In other words, following the loss of initial colour profile, both the ceramic and plastic brackets showed resistance to colour change. This is evidenced by slight ΔE changes in the heavy exposure mode in all the groups. These results infer that the length of exposure time beyond a certain threshold, will not lead to increased disparity, or that plastics and ceramic will react similarly when exposed the staining agents or the artificial saliva for an extended period of time, within the parameters of our study and the simulated six month period of testing.

It is intriguing to discuss the results of the individual bracket types. All brackets types in both study and control groups showed a varied degree of colour change, noted in their ΔE results. In all the study groups the ceramic brackets had less colour change than the plastic brackets. However, there was one exception in the plastic group. The study group of Spirit MB had the third lowest ΔE and performed better than some ceramic brackets. This result may be directly related to the fact that it is composed of a ceramic reinforced structure.

Another interesting finding of our study is that the structure of the ceramic brackets did not appear to influence the colour stability. This point can easily be visualized by the noting that Inspire Ice, a monocrystalline-structure bracket, has the lowest ΔE of the study ceramic study groups whereas Radiance, the other monocrystalline-structure bracket, had largest ΔE within the ceramic brackets. This may indicate that surface properties are of more importance to extrinsic staining than internal structure, but more research needs to be done on this topic (Lee 2008). When the brackets were exposed to artificial saliva, ceramic and plastic brackets behaved similarly. Although, the two largest ΔE values were recorded for plastic control brackets, the remaining 8 brackets fell in a range of ΔE 6-13. Lee 2008, was able to show a similar result, indicating that ceramic and plastic brackets will discolour in equivalent fashion when exposed to thermal cycling. Faltermeier, Behr and Müssig 2007, examined the effect of food product on the optical properties of plastic brackets. Faltermeier, Behr and Müssig 2007, exposed 4 brands of plastic brackets to coffee, tea, red wine and UV light and measured these differences with a spectrophotometer. The goal of this study was to determine which substances stained the most, how much time was required for stain to occur and which brackets would offer the greatest resistance to colour change. The brackets were exposed to the staining agents for either 24 or 72 hours, producing significant colour changes ΔE>3.7 in all exposure groups for 3 of the 4 brackets. This study also indicated that the increases in ΔE in the first exposure period from unexposed to 24 hours of exposure were larger in magnitude than they were in the subsequent exposure from 24 to 72 hours. Although the methodology of this study differs from the current study, three arguments are bolstered. First, that plastic brackets will undergo colour change when exposed to various spices and beverages. Second, that the susceptibility of brackets to stain is brand dependent. Finally, that even mild exposure to staining agents is sufficient to cause visually significant stain.

It should also be noted that the brackets in this study were of different shapes and sizes, which certainly may be a factor. The geometry, especially thickness can affect colour and any noted changes (Douglas and Przybylska 1999). The standards for colour measurement were recorded on flat and opaque materials which present many problems when assessing colour in dentistry (Johnson 2009). Ceramic veneers in aesthetic dentistry materials also demonstrated varying translucencies, and a range of translucency was reported in layered ceramic systems. This affected their definitive aesthetic appearance (Heffernan, Aquilino, Diaz et al. 2002). The differences in thickness between bracket brands and within the brackets themselves may have also had an impact on the colour measurements. Ozturk, Uludag, Usumez et al. 2007, stated that the mean ΔE^* values for two dental porcelain systems increased as the thicknesses increased. Another confounding variable of this study was the heterogeneous composition of some of the brackets. Many of the brackets, such as Damon3, Innovation-C, and Clarity contained metal components acting arch wire slots and self-ligation doors. It is not known if these components had any effect on the colour measurements. Efforts were made not to select areas near the metallic components, but the translucency and opalescence may have been impacted. For example, in aesthetic dentistry, metal substructures significantly affected the final colour of porcelain restoration (Kourtis, Tripodakis and Doukoudakis 2004). Photography of the brackets in this study required the use of illumination. This illumination revealed the reflective qualities of the brackets and is another variable that made reliable colour measurement problematic. When light is reflected from a surface, it is generally scattered in many directions, producing a pattern that is characteristic of the material. Identical materials can lead to different images, and different materials can lead to identical images (Fleming, Dror and Adelson 2003). Efforts were taken to limit the effect of reflection, including using a fixed light source emitting natural light, however it was noted that each brackets reflected the light differently. Strong mirror-like, specular reflectance can explain the bright appearance of different materials (Maia, D'Alba, and Shawkey 2010). The selection of these areas of reflection would simply be a measurement of the colour of the light source and not of the bracket (Lee, Yu, Lim et al. 2011). The highly reflective surface of the Inspire Ice and Radiance brackets may have affected our results despite our approach to avoid this bias.

The results of this study have provided insight into a relatively unevaluated area of research in orthodontics and certainly offer beneficial information for practicing clinicians. One of the drawbacks to this study as with all *in vitro* experiments is the difficulty in accurately reproducing the conditions of the oral cavity. Many efforts were made in the attempt to produce a natural oral environment, but it is a far more complex environment than one produced in a laboratory. An *in vivo* study would be ideal; however it adds many confounding variables including variation in diet, oral hygiene, mastication, and amount and composition saliva. Oral hygiene, specifically brushing was omitted from this study in an effort to avoid changing the surface morphology of the bracket. To obtain a better clinical picture of the colour changes of the brackets future research should be explore the effect of tooth brushing on their stain resistance.

The findings of this research prove the stated hypothesis that both ceramic and plastic brackets will have their optical properties altered according to increased consumption of various staining agents, *in vitro*.

Chapter VII

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Conclusions

This study was able to provide clear results that show that changes in the optical properties of both ceramic and plastic will occur when exposed to the beverages and spices tested, and to a lesser extent when in contact with artificial saliva *in vitro*. It can be deduced that overall the ceramic bracket discoloured to a lesser degree than the plastic bracket, although, exceptions were noted. No advantage in stain resistance can be bestowed on monocrystalline over polycrystalline ceramic brackets, but plastic-ceramic brackets hybrids show less colour change than plastic brackets. It also was noted that the majority of staining takes place after mild contact with the staining solutions and that further exposure although still producing changes will occur at the same rate as it would with exposure to artificial saliva.

Chapter VIII

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Table 1: Brackets investigated in this study

	Type	Brand Name	Company	Material	Batch #
I	Ceramic	Clarity	3M Unitek Monrovia CA.	Polycrystalline Alumina	BY2ZL
II	Ceramic	Inspire Ice	Ormco Orange CA.	Monocrystalline Alumina	1348
III	Ceramic	Radiance	American Orthodontics Sheboygan WI.	Monocrystalline Alumina	0101
IV	Ceramic	Innovation-C	GAC Dentsply Bohemia, NY	Polycrystalline Alumina	A372
V	Ceramic	NeoLeucent	Ortho Organizers Carlsbad, CA	Polycrystalline Alumina	2361
VI	Plastic	Damon 3	Ormco Orange CA	Hybrid Polycarbonate	03091
VII	Plastic	Vogue	GAC Dentsply Bohemia, NY	Polycarbonate	C351
VIII	Plastic	Silkon Plus	American Orthodontics Sheboygan WI.	Filler Reinforced Polycarbonate	1142
IX	Plastic	Spirit MB	Ormco Orange CA	Ceramic Reinforced Polycarbonate	04651
X	Plastic	Envision	Ortho Organizers Carlsbad, CA	Thermoplastic Polyurethane	3257

Table 2: Mean values of the colour parameters of the brackets after being exposed to test solutions

	L	*a*	*b*
Control	1.00	1.00	1.02
Cola	1.00	1.00	1.03
Coffee	0.97	1.00	1.04
Curry	0.97	1.00	1.05*
Tea	0.95	1.01*	1.07*
Tomato Juice	0.97	1.00	1.03
Wine	0.86*	1.04*	1.06*

*Indicates a significant difference ($p<0.05$) when compared to the control group

L= lightness

a= chromaticity coordinates in the red-green axis

b= chromaticity coordinates in the red-green axis

Table 3: Different consumption scenarios from light to moderate and corresponding amount of testing time for each group

	Exposures*/Week		Total hours for the whole experimental period (26 weeks)	
Consumption	Light	Heavy	Light	Heavy
Tea	7	14	30.3	60.7
Coffee	7	14	30.3	60.7
Curry Solution	0.25	1	1.08	4.3
Wine	3	7	13	30.3

*Each exposure is 10 minutes in duration.

Table 4: Colour parameters of the tested brackets

Group	Plastic											
	Control						Study					
	L		*a*		*b*		*L*		*a*		*b*	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
Phase 0	0.65	0.11	0.99	0.01	1.02	0.02						
Phase 1	0.55	0.09	0.98	0.01	1.01	0.02	0.40	0.07	1.00	0.01	1.04	0.01
Phase 2	0.56	0.09	0.98	0.01	1.01	0.02	0.41	0.07	1.00	0.01	1.04	0.01
Group	Ceramic											
	Control						Study					
	L		*a*		*b*		*L*		*a*		*b*	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
Phase 0	0.60	0.05	0.99	0.01	1.01	0.02						
Phase 1	0.61	0.06	0.98	0.01	1.00	0.01	0.53	0.07	0.99	0.01	1.04	0.01
Phase 2	0.63	0.08	0.99	0.01	0.99	0.01	0.55	0.07	0.99	0.07	1.03	0.01

SD indicates standard deviation

L= lightness

a= chromaticity coordinates in the red-green axis

b= chromaticity coordinates in the red-green axis

Phase 0= new unexposed brackets

Phase 1= brackets exposed to light consumption of spices/beverages

Phase 2 =brackets exposed to heavy consumption of spices/beverages

Table 5: Intra-group comparison of colour parameters between the study and control brackets at each phase

Ceramic									
	L			*a*			*b*		
	study	control	p	study	control	p	study	control	p
Phase I	0.53	0.61	<.0001	0.99	0.98	0.0002	1.04	1.00	<.0001
Phase 2	0.55	0.63	<.0001	0.99	0.99	0.722	1.03	0.99	<.0001
Plastic									
	L			*a*			*b*		
	study	control	p	study	control	p	study	control	p
Phase 1	0.40	0.55	<.0001	1.00	0.98	<.0001	1.04	1.01	<.0001
Phase 2	0.41	0.56	<.0001	1.00	0.98	<.0001	1.04	1.01	<.0001

L= lightness

a= chromaticity coordinates in the red-green axis

b= chromaticity coordinates in the red-green axis

Phase 1= brackets exposed to light consumption of spices/beverages

Phase 2 =brackets exposed to heavy consumption of spices/beverages

Table 6: Inter-group comparison of colour parameters between the ceramic and plastic brackets at each phase

Study									
	L			*a*			*b*		
	plastic	ceramic	p	Plastic	ceramic	p	plastic	ceramic	p
Phase I	0.40	0.53	<.0001	1.00	0.99	0.001	1.04	1.04	0.0039
Phase 2	0.41	0.55	<.0001	1.00	0.99	0.0772	1.04	1.03	0.0058
Control									
	L			*a*			*b*		
	plastic	ceramic	p	plastic	ceramic	p	plastic	ceramic	p
Phase 1	0.55	0.61	0.0236	0.98	0.98	0.5948	1.01	1.00	0.0541
Phase 2	0.56	0.63	0.0087	0.98	0.99	<.0001	1.01	0.99	0.0015

L= lightness

a= chromaticity coordinates in the red-green axis

b= chromaticity coordinates in the red-green axis

Phase 1= brackets exposed to light consumption of spices/beverages

Phase 2 =brackets exposed to heavy consumption of spices/beverages

Table 7: Inter-group comparison of differences: ceramic (study minus control) vs. plastic (study minus control) at each phase

Differences (study - control)									
	L			*a*			*b*		
	ceramic	plastic	p	ceramic	plastic	p	ceramic	plastic	p
Phase 1	-0.08	-0.15	0.0026	0.01	0.02	0.0048	0.04	0.03	0.8241
Phase 2	-0.08	-0.15	0.0011	0	0.02	<.0001	0.04	0.03	0.2838

L= lightness

a= chromaticity coordinates in the red-green axis

b= chromaticity coordinates in the red-green axis

Phase 1= brackets exposed to light consumption of spices/beverages

Phase 2 =brackets exposed to heavy consumption of spices/beverages

Table 8: Intra-group comparison of differences. phase 1 (study minus control) vs. phase 2 (study minus control)

Differences (study - control)									
	L			*a*			*b*		
	phase 1	phase 2	p	phase 1	phase 2	p	phase 1	phase 2	p
Ceramic	-0.08	-0.08	0.9731	0.01	0	0.0037	0.04	0.04	0.7374
Plastic	-0.15	-0.15	0.8722	0.02	0.02	0.9111	0.03	0.03	0.4767

L= lightness

a= chromaticity coordinates in the red-green axis

b= chromaticity coordinates in the red-green axis

Phase 1= brackets exposed to light consumption of spices/beverages

Phase 2 =brackets exposed to heavy consumption of spices/beverages

Table 9: Colour change (Δ*E*) for ceramic and plastic groups

	Δ*E* I		Δ*E* II		Δ*E* Total	
Groups	study	control	study	control	study	control
Ceramic	8	3	3	4	11	7
Plastic	25	11	1	2	26	13

Δ*E* I= colour change between unexposed brackets and light consumption of spices/beverages

Δ*E* II= colour change between light consumption and heavy consumption of spices/beverages

Δ*E* Total= colour change between unexposed brackets and heavy consumption of spices/beverages

Table 10: Colour change (Δ*E*) brand-specific

	Δ*E* I		Δ*E* II		Δ*E* Total	
Groups	study	control	study	control	study	control
Clarity	10	1	9	9	19	10
Innovation-C	4	3	2	4	6	7
Inspire Ice	2	9	4	4	6	13
Neolucent	8	0	7	8	15	8
Radiance	16	4	5	2	21	6
Damon3	21	17	5	5	26	22
Envision	29	4	4	2	33	6
Silkon Plus	34	11	3	1	37	12
Spirit MB	6	7	5	4	11	11
Vogue	33	21	6	2	39	23

Δ*E* I= colour change between unexposed brackets and light consumption of spices/beverages

Δ*E* II= colour change between light consumption and heavy consumption of spices/beverages

Δ*E* Total= colour change between unexposed brackets and heavy consumption of spices/beverages

Chapter IX

Page Number

Digital Analysis of Staining Properties of Clear Aesthetic Brackets

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Abstract

AIM: To analyse the staining properties of clear orthodontic brackets using a digital analysis. MATERIAL & METHODS: A total of 400 tooth-coloured brackets from 10 brands (5 ceramic and 5 plastic) were investigated. Cumulative discolouring effect of staining agents (tea, coffee, curry and red wine) were analysed at two consumption levels; light and heavy, based on a 6-month period of exposure. Study group brackets were immersed in the agents consecutively at 37°C. The control group was only exposed to artificial saliva. Samples were analyzed digitally to obtain the *L*, a*,* and *b** (lightness, red-green, and yellow-blue) colour readings. Using these values total colour change (ΔE*) at each level was also calculated. A general linear model (ANOVA) test was used for statistical comparisons. RESULTS: Significant differences were observed in *L*,* and *b** values of ceramic brackets between the staining agent and the control groups at all consumption levels ($p \leq .0001$). All the consumption levels had significant differences between the study and control groups of plastic brackets for *L*, a*,* and *b** colour codes ($p \leq .0001$) except the *L** value in the heavy consumption level. According to ΔE* values, ceramic brackets better resisted staining at mild and moderate levels. Total ΔE* values for ceramic and plastic brackets were 11 and 26, respectively. CONCLUSIONS: Both plastic and ceramic brackets showed changes in colour when exposed to heavy consumption of staining agents, with plastic brackets being the most affected.

Introduction

An increase has been reported in the number of adult patients who are seeking orthodontic treatment.[1] Accordingly, there is also high demand for aesthetically pleasing treatment options such as the use of clear brackets.[2] The first clear brackets in orthodontics were made of plastic, did not have adequate resistance to discoloration and were highly fragile under heavy occlusal and orthodontic forces.[3] Ceramic brackets in contrast have superior mechanical qualities to plastic brackets, in terms of hardness and stiffness, however the hardness characteristic can lead to abrasion of the occluding enamel.[4] In addition, ceramic brackets are quite brittle and this predisposes them to crack when stressed.[5] Both monocrystalline and polycrystalline alumina are used to manufacture ceramic brackets.[6] Monocrystalline brackets, however, have more optical clarity.[7] Current *in vitro* research showed that optical properties of both ceramic and plastic brackets were affected by thermal cycling while the crystal structure of the ceramic brackets did not influence colour stability.[8] Of concern, are the conclusions of Faltermeier *et al*.[9] who concluded that the consumption of red wine, coffee and tea caused undesirable optical changes in plastic brackets.

The investigation of colour changes can involve either one or a combination of three tools; spectrophotometers, colorimeters, and digital photograph analysis.[10] The analysis of digital photographs yielded statistically similar results to spectrophotometers when evaluating dental colour shade and indicates that the use of digital photography is worthwhile in the evaluation of colour changes due to the ease of application.[11] The analysis of colour in dentistry is generally defined by the Commission Internationale de l'Éclairage (CIE) Lab colour space. In this three-dimensional colour space with the three axes being L^*, a^* and b^*, the L* refers to the lightness. Its value ranges from 0 for perfect black to 100 for perfect white. The a^* refers to the chromaticity coordinates in the red–green axis. Positive a^* values reflect the red colour range and negative values indicate green colour range. The b^* corresponds to the chromaticity coordinate yellow–blue axis. Positive b^* values indicate yellow colour range while negative values indicate the blue colour range. Colour change is measured in terms of ΔE and measured by the equation: $\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$.[12] The proposed clinical perceptible limit for colour matching with the human eye is 3.7 ΔE units.[13,14] Different lighting conditions can have an effect on colour perception and a light source that approximates standard daylight is ideal colour analysis.[15]

To date no previous papers reported the cumulative effect of staining agents on the colour profile of clear brackets based on different exposure levels of stainants. Therefore, this study was undertaken to determine the long-term effects of certain spices, beverages and artificial saliva on the colour stability of both plastic and ceramic brackets using digital analysis in order to provide the clinician with information regarding how the physical properties of different types of aesthetic brackets may be altered in relation to the consumption time of various known stainants.

Materials and Method

10 different types of clear brackets, plastic and ceramic, were selected from various popular brands (Table 1). The cumulative discolouration by staining agents on

the brackets was determined at 2 exposure levels: mild and heavy. The stainants used in the study were: black tea (Tim Hortons, ON, Canada), regular black coffee (Tim Hortons. ON, Canada), curry paste (Patak's Madras Curry Paste, National Importers, B.C.,Canada) and red wine (Billygoat Hill Shiraz. Harvey River Bridge Estate, WA, USA).

Consumption scenarios, based on a 6-month equivalent period of total consumption and the total hours of testing for each consumption level are presented in Table 2. In the study group, 10 brackets of each type were immersed in a batch of 50 ml of the various staining solutions that was placed in an oscillating hot water bath (Percision Dubnoff Reciprocal Shaking Bath, Mandel Scientific Inc. ON, Canada) at a temperature of 37°C.. All of the brackets were then rinsed simultaneously, using a standard ultrasound bath (LR606, L&R, NJ, USA), in 50ml of de-ionized water at 37°C for 1 minute before being immersed in the next stainant solution. Control groups of 10 brackets of each type were immersed in synthetic saliva[Methyl-p-hydroxybenzoate, 2.00; sodium carboxymethyl cellulose, 10.0; KCl, 0.625; $MgCl_2.6H_2O$, 0.059; $CaCl_2.2H_2O$, 0.166; K_2HPO_4, 0.804; K_2HPO_4, 0.326 (units g/L)][16], and also placed in the oscillating hot water bath at 37°C, for the corresponding amount of times.

The colour reading protocol was based on the digital method proposed by Cal *et al.*[11] Digital images of brackets were taken against a black cardboard surface at the beginning of the study and then again after either saliva or staining agent exposure. A white standard photograph paper was also placed alongside the brackets as a calibration tool in order to eliminate environmental factors. A digital camera (D90, Nikon, Tokyo, Japan) was fixed on a tripod with 40-cm. object–camera distance oriented perpendicular to the test samples to acquire the digital image using a 6500K fluorescent light bulb (General Electric, ON, Canada), which emits the equivalent light spectrum of natural light. This image was saved in TIFF format and was later analysed by commercially available graphic software (Adobe Photoshop CS4, Adobe Systems Inc., San Jose, CA, USA). Fixed square areas that were 20 x 20 pixels in dimension were cropped from both the mesial and distal wings of each specimen. The L^*, a^*, b^* values of these areas were measured twice by using the histogram function of the software, and the mean values were used for each specimen. The experimental values were divided by the L^*, a^*, b^* values of the adjacent white photograph paper in order to eliminate the potential effects of the environmental factors, and the corrected L^*, a^*, b^* values of each specimen were recorded. The colour change (ΔE) was calculated using uncorrected L^*, a^*, b^* values for each subgroup between each consumption level.

Analysis of Variance (ANOVA) was used to analyze intragroup comparison of differences, study minus controls, (phase 1-phase 2) and intergroup comparison of differences, study minus controls (ceramic-plastic). Statistical significance was set at the 0.05 probability level.

Results

The colour measurements for the ceramic and plastic brackets groups are presented in Table 3. The mean and standard deviations of the corrected L^*, a^*, and b^* values are given for the study and control groups at each exposure level

The inter-group comparisons of differences between the ceramic and plastic brackets at each phase are presented in Table 4. *L** and *a** values showed greater colour changes for plastic brackets, which differed significantly at the start and at the end of the phases ($p<0.05$). Table 5 shows the intra-group group contrasts. *L** and *b** values showed no significant differences between Phase 1 and Phase 2. However, the differences in *a** values for the ceramic group were significant ($p=0.0037$).

Table 6 shows the overall colour changes for plastic and ceramic brackets. Ceramic brackets had less colour change than plastic brackets at the end of phase 1 for both the study and control groups. However, as the consumption time increased, the rate of colour change decreased for the plastic brackets. The total ΔE values for the whole experiment showed that ceramic brackets are much more resistant to the cumulative effect of staining agents than plastic brackets. Colour changes of individual brackets types are shown in Table 7. The variability of the range of ΔE values demonstrated that discolouration of clear brackets is highly brand-specific.

Discussion

The results of this study indicate that the ceramic brackets in general show less colour change than plastic brackets. Their mean ΔE values were 15 and 6 units below the averages of the plastic brackets and control groups respectively. The colour change was more apparent during the initial phase of exposure in each group indicating that once a certain threshold was reached both the ceramic and plastic brackets showed better resistance to colour change. This is evidenced by lesser ΔE changes between the light and heavy exposure groups. Our results are in agreement with a previous study [9] that showed colour changes in plastic brackets exposed to staining solutions were larger from a virgin state to mild exposure than between mild and heavy exposure. It was also shown that even mild exposure to staining agents is sufficient to cause a visual stain.[9] Even when the brackets were exposed to artificial saliva, the colour profile of both ceramic and plastic brackets were negatively affected. Lee [8] showed a similar result, indicating that ceramic and plastic brackets will discolour in an equivalent fashion when exposed to thermal cycling. This may be related to the loss of surface finishing characteristics of the materials when exposed to the washing effect of saliva.

Many structural differences remain even within the plastic and ceramic bracket groups. Ceramic brackets are either made of monocrystalline or polycrystalline whereas plastic brackets contain an array of materials such as polycarbonate and polyurethane. Furthermore, many of the plastic brackets are subjected to further manufacturing enhancements such as reinforcement with surface treatments and the addition of various fillers, which may explain the stain resistance exhibited by the Spirit MB brackets as opposed to all the other plastic brackets. Although constructed of polycarbonate, Spirit MB brackets are reinforced with ceramic that potentially may add better resistance to staining. However, the crystal structure of the ceramic brackets did not seem to influence the colour stability. This can be visualized by the fact that Inspire Ice and Radiance, both monocrystalline-based brackets, respectively had the lowest and largest ΔE values within the ceramic study groups. Our finding is in agreement with Lee [8] , who found no relationship between stain resistance and the crystal structure of the bracket.

The critical features of colour analysis are translucency and opalescence. Translucency is the property of a substance that permits the passage of light.[17] Opalescence refers to a light scattering occurrence found in translucent materials wherein a blue colour is produced due the scattering of short wavelength light.[18] One may be able to attribute the changes in ΔE to a loss of opalescence, which may not necessarily relate to deterioration in appearance. Opalescence, therefore, could have lead to the production of false negatives in the results. No attempt was made to mechanically debride the brackets, before, during or after this study. Conversely, one must be aware that mechanical debridement of the brackets may yield alternative results and the influence of brushing on colour change may be worthy of future exploration. Another variable that must be considered when extrapolating these results to clinical performance is the potential of orthodontic bonding adhesives to stain.[19,20] Staining of the adhesive may potentially alter the appearance of the translucent brackets.

Digital photography of the brackets used in this study required the use of illumination. This illumination revealed the reflective qualities of the brackets and is another variable that may have influenced the results. When light is reflected from a surface, it is generally scattered in many directions, producing a pattern that is characteristic of the material. Identical materials can lead to different images, and different materials can lead to identical images.[21] Efforts were taken to limit the effect of reflection, including using a fixed light source emitting natural light; however, it was noted that the individual brackets reflected the light differently. Strong mirror-like specular reflectance, can explain the bright appearance of different materials.[22] The selection of these areas of reflection would simply be a measurement of the colour of the light source and not of the bracket.[23] Some brackets have highly reflective surfaces like Inspire Ice and Radiance and this may have also contributed to variations in our colour readings.

This study has explored a relatively unevaluated area of research in orthodontics and offers beneficial information for practicing clinicians. As with all *in vitro* experiments one of the greatest challenges is the difficulty in accurately reproducing the conditions within the oral cavity such as variation in diet, plaque, effects of mastication, and the amount and composition saliva. Brushing was omitted in this study in an effort to avoid altering the surface morphology of the brackets. Future research should include the effects of a standard tooth brushing protocol on the stain resistance.

Conclusions

Changes in the optical properties of both ceramic and plastic brackets occur when exposed to the beverages and spices and to a lesser extent when brackets are in contact with artificial saliva. Ceramic brackets discoloured to a lesser degree than the plastic brackets. No advantage in stain resistance can be bestowed on monocrystalline over polycrystalline ceramic brackets, but hybrid plastic-ceramic brackets show less colour change than plastic brackets. The majority of staining takes place after mild contact with the staining solutions yet further exposure produces colour changes equivalent to artificial saliva. Ultimately, even in the absence of stainants, clear brackets could discolour in the intra-oral environment.

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Table 1: Brackets investigated in this study

	Type	Brand Name	Company	Material	Batch #
I	Ceramic	Clarity	3M Unitek Monrovia CA.	Polycrystalline Alumina	BY2ZL
II	Ceramic	Inspire Ice	Ormco Orange CA.	Monocrystalline Alumina	1348
III	Ceramic	Radiance	American Orthodontics Sheboygan WI.	Monocrystalline Alumina	0101
IV	Ceramic	Innovation-C	GAC Dentsply Bohemia, NY	Polycrystalline Alumina	A372
V	Ceramic	NeoLeucent	Ortho Organizers Carlsbad, CA	Polycrystalline Alumina	2361
VI	Plastic	Damon 3	Ormco Orange CA	Hybrid Polycarbonate	03091
VII	Plastic	Vogue	GAC Dentsply Bohemia, NY	Polycarbonate	C351
VIII	Plastic	Silkon Plus	American Orthodontics Sheboygan WI.	Filler Reinforced Polycarbonate	1142
IX	Plastic	Spirit MB	Ormco Orange CA	Ceramic Reinforced Polycarbonate	04651
X	Plastic	Envision	Ortho Organizers Carlsbad, CA	Thermoplastic Polyurethane	3257

Table 2: Different consumption scenarios from light to heavy and corresponding amount of testing time for each group

	Exposures*/Week		Total hours for the whole experimental period (26 weeks)	
Consumption	Light	Heavy	Light	Heavy
Tea	7	14	30.3	60.7
Coffee	7	14	30.3	60.7
Curry Solution	0.25	1	1.08	4.3
Wine	3	7	13	30.3

*Each exposure is 10 minutes in duration

Table 3: Colour parameters of the tested brackets

Group	Plastic											
	Control						Study					
	L		*a*		*b*		*L*		*a*		*b*	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
Phase 0	0.65	0.11	0.99	0.01	1.02	0.02						
Phase 1	0.55	0.09	0.98	0.01	1.01	0.02	0.40	0.07	1.00	0.01	1.04	0.01
Phase 2	0.56	0.09	0.98	0.01	1.01	0.02	0.41	0.07	1.00	0.01	1.04	0.01
Group	Ceramic											
	Control						Study					
	L		*a*		*b*		*L*		*a*		*b*	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
Phase 0	0.60	0.05	0.99	0.01	1.01	0.02						
Phase 1	0.61	0.06	0.98	0.01	1.00	0.01	0.53	0.07	0.99	0.01	1.04	0.01
Phase 2	0.63	0.08	0.99	0.01	0.99	0.01	0.55	0.07	0.99	0.07	1.03	0.01

SD indicates standard deviation

L= lightness

a= chromaticity coordinates in the red-green axis

b= chromaticity coordinates in the red-green axis

Phase 0= new unexposed brackets

Phase 1= brackets exposed to light consumption of spices/beverages

Phase 2 =brackets exposed to heavy consumption of spices/beverages

Table 4: Inter-group comparison of differences: ceramic (study minus control) vs. plastic (study minus control) at each phase

Differences (study - control)									
	L			*a*			*b*		
	ceramic	plastic	p	ceramic	plastic	p	ceramic	plastic	p
Phase 1	-0.08	-0.15	0.0026	0.01	0.02	0.0048	0.04	0.03	0.8241
Phase 2	-0.08	-0.15	0.0011	0	0.02	<.0001	0.04	0.03	0.2838

L= lightness

a= chromaticity coordinates in the red-green axis

b= chromaticity coordinates in the red-green axis

Phase 1= brackets exposed to light consumption of spices/beverages

Phase 2 =brackets exposed to heavy consumption of spices/beverages

Table 5: Intra-group comparison of differences. phase 1 (study minus control) vs. phase 2 (study minus control)

Differences (study - control)									
	L			*a*			*b*		
	phase 1	phase 2	p	phase 1	phase 2	p	phase 1	phase 2	p
Ceramic	-0.08	-0.08	0.9731	0.01	0	0.0037	0.04	0.04	0.7374
Plastic	-0.15	-0.15	0.8722	0.02	0.02	0.9111	0.03	0.03	0.4767

L= lightness

a= chromaticity coordinates in the red-green axis

b= chromaticity coordinates in the red-green axis

Phase 1= brackets exposed to light consumption of spices/beverages

Phase 2 =brackets exposed to heavy consumption of spices/beverages

Table 6: Colour change (ΔE) for ceramic and plastic groups

	ΔE I		ΔE II		ΔE Total	
Groups	study	control	study	control	study	control
Ceramic	8	3	3	4	11	7
Plastic	25	11	1	2	26	13

ΔE I= colour change between unexposed brackets and light consumption of spices/beverages

ΔE II= colour change between light consumption and heavy consumption of spices/beverages

ΔE Total= colour change between unexposed brackets and heavy consumption of spices/beverages

Table 7: Colour change (ΔE) brand-specific

	ΔE I		ΔE II		ΔE Total	
Groups	study	Control	study	control	study	control
Clarity	10	1	9	9	19	10
Innovation-C	4	3	2	4	6	7
Inspire Ice	2	9	4	4	6	13
Neolucent	8	0	7	8	15	8
Radiance	16	4	5	2	21	6
Damon3	21	17	5	5	26	22
Envision	29	4	4	2	33	6
Silkon Plus	34	11	3	1	37	12
Spirit MB	6	7	5	4	11	11
Vogue	33	21	6	2	39	23

ΔE I= colour change between unexposed brackets and light consumption of spices/beverages

ΔE II= colour change between light consumption and heavy consumption of spices/beverages

ΔE Total= colour change between unexposed brackets and heavy consumption of spices/beverages