EC DENTAL SCIENCE
Research Article

Investigation the Effect of the Type of Substrate, Veneering Techniques and Repeated Firing Cycles on Color Stability of Ceramic Restorations

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Received: December 06, 2016; **Published:** December 12, 2016

Abstract

Statement of the problem: Color stability is an important factor to ensure the long-term clinical success of ceramic restorations. There is a lack of information on how color is affected by fabrication procedures, such as the type of substrate, the number of Firings and veneering techniques.

Aim of study: To evaluate the effect of type of substrate, veneering fabrication method and repeated firing cycles on the color change of Y-TZP zirconia & metal ceramic restorations.

Material and Methods: A total of twenty ceramic specimens were constructed with a 10 mm diameter and 1.5 mm thickness; the specimens were divided according to the ceramic types into 2 groups: Metal ceramic specimens and Y-TZP Zirconia specimens. Each group was subdivided according to the veneering technique into 2 subgroups ($n = 5$): Layering and pressing techniques. All specimens were measured with a spectrophotometer for base line data and repeated firing cycles (1, 2 and 3). Color readings were obtained with a spectrophotometer, and L*, a*, and b* coordinates and total color variation (ΔE) were calculated, recorded, tabulated and submitted to statistical analysis analyzed (2-way ANOVA, The Duncan test was used to perform multiple comparisons, $p = 05$).

Results: For metal ceramic specimens, differences for the L* coordinates were significant ($P < 0.05$) only for the group submitted to 3 firings. With respect to the all ceramic specimens, smaller L* coordinates were obtained for greater a* and b* coordinates, indicating that the greater the number of firings, the darker and more reddish/yellowish the specimen. All ΔE values, for all groups, were below 1.0. All-ceramic specimens submitted to 3 firings presented ΔE means differing statistically ($P < 0.05$) from those of the metal ceramic group.

Conclusions: The type of substrate, the technique of veneer fabrication and number of firings affected the color stability of the ceramic material tested and the choice of any factor should be highly considered.

Keywords: *Veneering techniques; Firing Cycles; Color Stability; Ceramic Restorations*

Introduction

In recent years, esthetic dentistry has become more prevalent because of increasing demand from patients and the development of new techniques and materials that improve the clinician's and technician's abilities to provide esthetic treatment [1].

Although metal ceramic crowns in fixed dental prostheses (FDPs) can still be considered a common choice, particularly in the posterior region of the jaws due to increasing occlusal load [2], The emergence of all ceramic systems in crowns and fixed partial dentures are steadily increasing due to increased the patient demand for metal free restorations [3].

A successful color match is an important aspect of any esthetic dental restoration [4]. Since natural enamel has inherent translucency, it is important that ceramic restorations reproduce the translucency and color of the natural teeth [5]. However, the final color match of porcelain crowns to adjacent natural dentition remains problematic [4].

The color replication process for fixed restorations consists of a shade matching phase followed by a shade duplication phase [7]. Difficulties related to color matching may arise from the use of inadequate shade guides [8], different types of metal alloys and varying compositions of ceramic materials [9,10] the thickness of the ceramic layer [11,12] firing parameters and temperatures [13-15] and the number of firing, [13,14,16]. Porcelain brand [17-19], batch [18], condensation technique [18], dentin thickness [9,12,20] and number of porcelain firings [20,21], can affect the definitive shade of an esthetic restoration.

The metal framework and the layer of opaque porcelain needed for masking the underlying metal grayish shade are likely to introduce a significant limitation for the esthetic result due to the absence of translucency, especially when a clear tooth color is to be reproduced: in fact, metal-ceramic restorations can only absorb or reflect light, while dental tissues show a high degree of translucency [22].

For metal ceramic systems, some studies have been shown no or minimal effect of repeated firings on the color of metal ceramic systems [21,23,24] while other studies reported perceptible color changes [18].

Recently a new generation of ceramics has been introduced for veneering metallic and non-metallic cores. It was developed following the idea of pressable all ceramic systems. First, a metal substructure is waxed and cast [25]. After the casting, has been opaqued, a complete contour wax pattern is fabricated, and the ceramic is heat-pressed onto the undercasting [26-28].

Pressable ceramics are known to possess many desirable properties, e.g., less porosity and better marginal adaptation, but little data are available in the literature regarding ceramics pressed to metal (press-on metal, POM) versus conventional veneering techniques [25].

Since it was introduced in Dentistry, the polycrystalline zirconium dioxide (zirconia) resulted particularly attractive in prosthodontics, due to its excellent mechanical properties and improved natural-looking appearance compared to metal-ceramics [29].

Although being many types of zirconia-based ceramics available, to date three zirconia-containing systems have been more or less extensively used for dental applications; Two of them are by-phasic materials: the “in-Ceram zirconia” (ZTA) and the magnesium partially stabilized zirconia (Mg-PSZ); the third most used, is the “Yttria partially stabilized tetragonal zirconia polycrystal” (3Y-TZP), a monophasic material [29,30].

Yttria-stabilized tetragonal zirconia (Y-TZP) is used as a core material in all ceramic dental restorations [31], implant superstructures [32] and orthodontic brackets [33]. The mechanical properties of zirconia that were proved to be higher than those of all other ceramics for dental use, with a fracture toughness of 6 - 10MPa/m1/2, a flexural strength of 900-1200 MP a and a compression resistance of 2000MPa [34], are due to the transformation toughening mechanism, similar to that observed in quenched steel.

Zirconia dental frameworks can be produced according to two different techniques: “soft machining” of Pre-sintered blanks or “hard machining” of fully sintered blanks [35]. The soft machining process is the most diffused manufacturing system for 3Y-TZP, based on milling of pre-sintered blanks that are fully sintered at a final stage to produce the zirconia cores [35].

Unfortunately, current processing technologies cannot make zirconia frameworks as translucent as natural teeth, Therefore, zirconia cores or frameworks are generally veneered with porcelain to achieve esthetics that is more acceptable. Traditionally, veneering ceramics are layered on zirconia core materials to establish an optimum esthetic outcome. An alternative technique is to press veneering ceramics to the zirconia core [36].

For ceramic core systems, Color stability after repeated number of firings was shown to be clinically acceptable [16,13,37,38]; however, perceptible color changes were reported for only one ceramic-core system investigated [37]. Ceramic-core specimens subjected to a repeated number of firings exhibited better color stability compared to metal ceramic specimens, despite the imperceptible color changes [39].

Uludag., *et al*. [13] studied the influence of ceramic thickness and number of firings on the color of ceramic systems, and reported perceptual color changes in L*a*b* color values as the number of firings increased. The authors stated that an increase in the number of firings resulted in a decrease in L* values and an increase in a* and b* color values of In-Ceram and IPS Empress Specimens with different dentin ceramic thicknesses.

The CIE L*a*b* color order system was developed by the Commission Internationale de l'Eclairage (CIE, International Commission on Illumination) in 1931. It is used frequently in color research and is based on the color standardization of light sources and observers [40].

The strength of this system is in its ability to be clinically interpreted, as equal differences across the CIE L*a*b*color space (color differences, or ΔE) represent approximately uniform steps in human color perception, improving the interpretation of color measurement [41].

Currently, there are several electronic shade-matching instruments available for clinical use. These devices can be classified as RGB devices, digital cameras, colorimeters and spectrophotometers or combinations of these [42].

There are many clinical spectrophotometric systems that can be used for color measurements and color difference of the teeth *in vivo*. However, the best research spectrophotometer uses what is called "spherical optics", in which the object or specimen is placed inside the equipment and exposed to light from many different angles and directions and this gives the accurate results of the reflectance or transmittance properties of the object [42]. On the other hand, spectrophotometers for clinical uses cannot achieve this different degree of light exposure angles since the tooth cannot be placed inside the device and instead light is directed at the tooth surface [42], excellent repeatability [43], a longer working life than colorimeters and are unaffected by object metamerism [44,45].

The purpose of this study was to evaluate the effects of the number of firings, type of substrate and the veneering techniques on the color stability of dental ceramic.

The null hypotheses of this study are that metal ceramic restorations would present greater color change than all ceramic restorations; the veneering technique would not affect the shade reproducibility of ceramic restorations. and that increasing the number of firings would cause greater color changes that will affect the final shade of ceramic restorations.

Materials and Methods

Methods

Grouping of specimens: A total of twenty disc-shaped specimens were constructed. The specimens were divided into two groups according to the ceramic type (metal ceramic and zirconia). Each group was divided into two subgroups according to the veneering technique (layering and pressing).

Mold construction: Specially designed brass mold was constructed for this study to produce a disc shaped specimens. The brass mold was prepared in 2 pieces. The first upper piece had a 10-mm-diameter cylindrical cavity in the middle. The second lower piece had a piston that was adjusted to the first piece with a screw system so that it could rise and descend in the cavity. The outer surface of the first piece was divided into 10 equal units. When it was calibrated, the piston moved downward with a sensitivity of 0.1 mm. The piston descended 1.0 mm with 1 turn of the screwed lower piece. The required metal, wax pattern and ceramic thickness was provided by adjusting the depth of the cavity above the piston by turning the screwed lower piece the necessary amount.

Material	Composition	Lot number	Manufacture
Protechno-N nickel-chromium alloy	- Nickel 62 – 77% - Chromium 11 – 22% - Molybdenum 3 – 6% - aluminum 2 – 6% - Silicon and manganese	3547839	Jelenko, San Diego, Calif
IPS InLine/IPS InLine POM opaquer	Paste: Liquid:	L47540 (Pa), L28110 (L)	Ivoclar Vivadent
IPS InLine Dentine A3	Leucite ceramic based on silicate glasses and feldspar	L53664 (PO) L39576 (L)	Ivoclar Vivadent
IPS InLine POM Ingot A3	Leucite ceramic based on silicate glasses	S37740	Ivoclar Vivadent
IPS InLine/IPS InLine POM Glaze	oxides, glycols, butandiol	L49281 (Pa) L59382 (L)	Ivoclar Vivadent
ZirkonZhan blank	Y- TZP	……………….	ZirkonZhan
IPS e.max Ceram ZirLiner	Fluoroapatite glass ceramic	L32974 (Po), H32800 (L)	Ivoclar Vivadent
IPS e.max Ceram A3 Dentin	low-fusing nano-fluorapatite glass-ceramic	L11240 (Po) L06423 (L)	Ivoclar Vivadent
IPS e.max Zirpress Ingots A3	Fluoroapatite glass-ceramic ingot	S13946	Ivoclar Vivadent
IPS e.max Ceram Glaze		L60044(Pa) K49036 (L)	Ivoclar Vivadent
Opalescence PF 15%	- Carbamide peroxide - Potassium nitrate - Fluoride ion	------------	Ultradent, USA

Table 1: *Materials used in the study.*

Metal ceramic specimens: Ten disc-shaped wax patterns 0.5 mm thickness and 10 mm in diameter were prepared in the cylindrical custom made brass mold. The mold was adjusted to 0.5 mm thickness. Casting wax (Pro-art premium; Ivoclar Vivadent) was melted and poured into the mold cavity until filled and a glass plate was placed onto the upper layer to obtain a flat surface.

After the wax cooled to room temperature, excess wax was removed with a surgical blade. The pattern was removed and checked for any defects and corrected free hand or replaced. Care should be taken to avoid bubbles formation within the pattern.

After which, Wax sprues were attached to the patterns. Patterns were invested with a phosphate-bonded investment, allowed to set and placed in a burnout furnace and burnout program was started (Start at room temperature, heat up to 930˚C, rate of temperature increase 5˚C/ min, Holding time at final temperature ,930˚C, 30 minutes).

Figure 1: *Diagram of mold.*

At the end of the burnout cycle, the investment was moved to the centrifugal casting machine and a nickel-chromium-base metal alloy (Protechno-N nickel-chromium alloy Jelenko, San Diego, Calif) was placed in the crucible in the casting machine. The investment ring was placed into the machine and casting was carried out After casting was completed, divesting was carried out and sprues were removed using a thin carborundum disk and bench motor. The surface to be veneered was smoothed using a finishing carbide bur.

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The thickness of each specimen was then verified with a caliper accurate to 0.1 mm at 4 different points, and specimens that did not meet the dimensional criteria were replaced with appropriately sized new specimens. Airborne-particle abrasion with 50 μm aluminum oxide particles for 10 seconds at 2 MPa and 10 cm distance was performed on the surfaces to be veneered using a customized tool. Subsequently, the metal discs were cleaned under running water and dried. Finally, specimens were placed on the furnace (Programat EP 5000; Ivoclar Vivadent) and oxidation firing under vacuum was performed according to the manufacturers' instructions.

Before layering and pressing of the veneering ceramics, first and second opaque firings IPS InLine/IPS InLine POM opaque for each veneering ceramic were performed according to the manufacturers' instructions. The mold cavity was adjusted to 0.6 mm thickness and the metal specimen was placed into the mold cavity. This will provide a thickness of 0.1 mm for opaque application (104). The opaquer paste IPS In Line opaque. was extruded from the syringe and mixed thoroughly on the mixing pad. The first opaquer layer was applied thinly into the surface and fired in the furnace. The second opaquer layer was applied in such a way that the metal framework is entirely covered with opaquer and then fired.

The specimens were then divided into 2 groups, according to the type of veneering process (n = 5); Group LZI and group PZI

Layered zirconia group (LZI): Five zirconia discs were veneered with IPS e.max Ceram IPS e.max Ceram; Ivoclar Vivadent. shade A3, applied on the cores with thickness of 0.9 mm.

The mold cavity was adjusted to 1.5 mm thickness and zirconia disk was placed into the mold cavity with the surface to be veneered upward. This will provide a thickness of 0.9 mm for the veneering ceramic. Dentine and incisal veneering porcelain was mixed, condensed, hand vibrated, excess moisture was removed with absorbent paper to produce minimal shrinkage during processing and firing was carried out in a vacuum furnace.

Excess ceramic was adjusted with diamond rotary cutting instrument.

The thickness of each specimen was verified with a caliper with an accuracy of 0.01 mm. Glaze paste was applied and glaze firing was performed for all specimens.

Pressed zirconia group (PZI): The mold cavity was adjusted to 1.5 mm thickness and the metal specimen was placed in the mold cavity with opaqued surface upward. This would provide a thickness of 0.9 mm for veneering ceramic. Wax was melted and poured into the mold cavity until filled.

A glass plate was placed on the upper layer to obtain a flat surface. After the wax cooled to room temperature, excess wax was removed with a surgical blade and the waxed metal specimen was checked for any defects and corrected. Sprues were attached to the top of the wax patterns and then wax-zirconia specimens were invested in a phosphate-bonded investment within the same pressing ring. The ring was then placed in the preheated oven and wax elimination was carried out (Start at room temperature, heat to 850˚C, rate of temperature increase 5˚C/ min, Holding time at final temperature, 850˚C, 90 minutes). At the end of burnout cycle, the ceramic ingot IPS e.max. shade A3 was inserted into the sprue entrance of the hot investment ring and the powder-coated IPS Alox Plunger was placed over it. The hot ring was placed in the press furnace.

The pressing machine was closed and the selected program started. Once the press program is completed, the hot investment ring was placed on the cooling grid and allowed it to cool to room temperature. Divesting was carried out, sprues were separated and attachment points were smoothed. Specimens were sandblasted and finally, cleaned under running water. Glaze paste was applied and glazing firing was carried out for all specimens.

Color measurement

The color of each specimen was measured with a spectrophotometer (Perkin Elmer lambda 750 UV/Vis, USA). This system captures the color coordinates using a D65 illuminant (color temperature 6500˚ Kelvin; a mathematical construct equivalent to average daylight in the Northern Hemisphere).

The Lab values of all specimens were measured with the glazed surface facing against the light source. Repeated firings (1,2 and 3) were performed, at glazing program, for each group according to manufacturer instructions and the specimens of each group were measured after each firing cycle. The instrument calibration was evaluated after measurement of each group.

The L, a and b values were recorded for each specimen, and transferred to a personal computer for analysis and calculation of ΔE after each firing cycle and between cycles with the use of the following equation (132).

$\Delta E = [(\Delta L^*) 2 + (\Delta a^*) 2 + (\Delta b^*) 2]1/2$
$\Delta E = [(L1- L2) 2 + (a1- a2) 2 + (b1- b2) 2]1/2$

The L* coordinate is a measure of the lightness-darkness of the specimen. The a* coordinate is a measure of the Chroma along the red green axis and the b* coordinate is a measure of the Chroma along the yellow-blue axis. ΔL*, Δa* and Δb* are the differences in the CIE color-space parameters of the 2 colors.

Repeated measures analysis of variance (ANOVA) was used to analyze the data (number of firings, veneering techniques and the type of substrate) for significant differences. The Duncan test was used to perform multiple comparisons.

Results

Results of color changes after repeated firing

The results of the ANOVA of L*a*b* color parameters (number of firings and veneering ceramic techniques and the type of substrate) for all ceramic systems are listed in Table 2.

Parameter	Effect	Pillai's Value	Numerator *df*	Denominator *df*	*F*	*P*
L*	Number of firings	5.922	3	14	119.3	0.0001**
	Number of firings x veneering ceramic x Type of substrate	1.977	9	48	39.84	0.0001**
a*	Number of firings	0.015	3	14	139.9	0.0001**
	Number of firings x veneering ceramic x Type of substrate	0.006	9	48	60.46	0.0001**
b*	Number of firings	0.061	3	14	246.7	0.0001**
	Number of firings x veneering ceramic x Type of substrate	0.053	9	48	214.1	0.0001**

Table 2: *Multivariate test results based on 2-factor repeated-measures ANOVA for changes in color coordinates after repeated firings.*
***highly significant at 01 levels of probability*

The L*, a* and b* values of all ceramic types were significantly affected by the number of firings (1, 2, or 3 firings) ($P < 0.05$) and veneering porcelain type ($P < 0.05$). Significant interactions were present in L* a* b* ($P = 0.0001$) value between firing number and ceramic type.

The mean L, a and b and standard deviations values and multiple comparison test (Duncan test) results for each individual parameter tested are presented in Table 3 (Figure 2).

Number of firings	(ΔE) LMI	(ΔE) PMI	(ΔE) LZI	(ΔE) PZI
After 1 firing	2.5266	1.2386	3.1361	0.6640
After 2 firing	1.6262	0.2359	2.1407	0.3996
After 3 firing	0.6468	1.1392	1.1109	1.0347
1 – 2	0.9058	1.3198	1.0461	0.9429
1 – 3	1.8908	0.2809	2.0347	0.3787
2 – 3	0.9870	1.2661	1.0303	1.3100

Table 3: *Mean ΔE values of veneering ceramic techniques and type of substrate after repeated firings.*

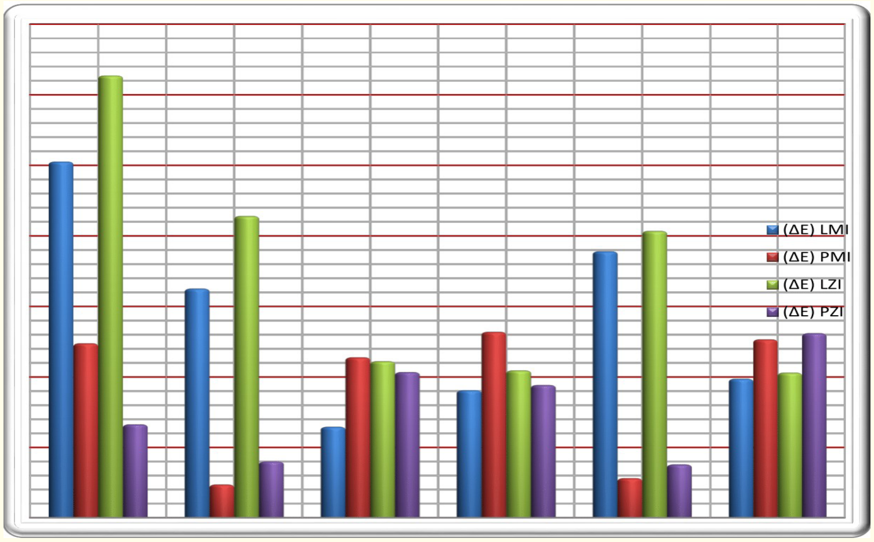

Figure 2: *ΔE values for veneering techniques, the type of substrate after repeated firing.*

Mean and standard deviation values and multiple comparison test results for L* parameter tested showed that the LMI and LZI, an increase in the number of firing caused a decrease in the L* values. Whereas, for PMI and PZI specimens, repeated firing caused an increase in the L* values.

The a* values for LMI, LZI and PZI specimens, decreased after repeated firing and increased for PMI specimens.

For LMI, PMI and PZI specimens, the b* values decreased as a result of increasing the number of firing. Whereas for LZI, the b* values increased after repeated firing.

All ceramic groups had statistically significant differences for all of the parameters tested for the individual number of firings ($P < 0.001$).

The ΔE values were calculated for each group (Table 3, figure 2) to determine the mean color difference (ΔE), depending on repeated firings.

Discussion

Several factors could result in the esthetic failure of ceramic restorations, and many are associated with restoration fabrication procedures, such as the number of ceramic firing (109). This factor could be the cause of the difference between the target color and the actual color reached in the definitive restoration [39]. Depending on the magnitude of this color difference, the restoration may be considered unsatisfactory and require replacement [46].

An *in vitro* study in any area of dentistry represents an attempt to simulate clinical conditions, but no matter how well an investigation is designed, it cannot reproduce all the relevant clinical features. It does, however, allow examination of factors that influence clinical performance, but that cannot be tested *in vivo* for ethical or practical reasons. An *in vitro* study may also be expected to highlight clinical technique variables of significance, and the findings of such studies are therefore of direct clinical application.

In the current study two ceramic systems were used, metal ceramic and zirconia, with two veneering techniques (layering and pressing). The Conventional layering technique for both metal and zirconia based restorations is still the most common and widespread in the market. However, pressing ceramic to metal or zirconia show less porosity and better marginal adaptation.

In the current study, specimens were constructed with a fixed 10 mm diameter as made by other researches for color difference [16,13] and 1.5 mm thickness as the average thickness for metal and zirconia frameworks are 0.5 mm with 1 mm veneering ceramic thickness.

The spectrophotometer used in the current study is the best for research uses in which the object or specimen is placed inside the equipment and exposed to light from many different angles and directions and this gives the accurate results of the reflectance or transmittance properties of the object [42]. Moreover, Spectrophotometers have excellent repeatability [43], a longer working life than colorimeters and other electronic shade matching devices and are unaffected by object metamerism [44,45].

In the current study, the color of all ceramic specimens were measured and recorded as a baseline data and then subjected to repeated firing cycles (1, 2 and 3) to simulate the chairside adjustment and to evaluate the effect of these firing cycles on the final color of the ceramic restorations.

CIE L*a*b*color system was used in this study to measure the color of specimens and to evaluate the color difference (ΔE) after repeated firing. The strength of this system is in its ability to be clinically interpreted, as equal differences across the CIE L*a*b*color space (color differences, or ΔE) represent approximately uniform steps in human color perception, improving the interpretation of color measurements [41].

The color difference value (ΔE) represents the numerical distance between L*a*b* coordinates of 2 colors. Under ideal observation conditions, when the ΔE value of 2 colors is less than 1 unit ($\Delta E < 1$), a color match between 2 colors can be judged. When measured color differences are within the 1 to 2 ΔE unit range, correct judgments are made frequently by skilled observers. When ΔE values are greater than 2 ΔE units, all observers can apparently detect color difference between 2 colors. The clinically acceptable limit of the color difference value is considered 3.7 ΔE unit [47].

The hypothesis of this study that multiple firing cycles will affect the final shade of ceramic restorations was accepted. The result of this study showed perceptible but clinically acceptable color changes (ΔE) for the tested four ceramic systems after repeated firings as there were significant differences in color changes within all groups.

The results of current study are in agreement with, Uludag., *et a*l. [38] who investigated the effect of repeated firing on the color of DC-Zirkon and Sahin., *et al*. [16] who investigated the effect of repeated firings on the color of an alumina ceramic system.

However, the results of this study are in disagreement with Barghi [15] who studied the effect of repeated firing on four porcelain types, Barghi and Goldberge [23] who investigated the effect of repeated firing on the color of vacuum fired compared to air-fired porcelain and Barghi., *et al*. [48] who investigated the effect of repeated firing on the color of one type of porcelain.

Color changes after repeated firing are multifactorial causes; may be attributed to the increase in density caused by the decrease of air bubbles trapped inside the porcelain [15]. Color changes may be also attributed to changes in translucency related to verification of the veneering porcelain after additional firings [38,49]. color instability of metal oxides during firing, which can affect the resulting color of ceramic [38]. Several studies [14,50,51] suggested that certain metal oxides are not color stable after they are subjected to firing temperatures and color changes of surface colorants after firing have demonstrated pigment breakdown at firing temperatures. Crispin., *et al*. [50] and Lund and Piotrowski [51] reported that yellow and orange hue stains were the least color stable at the manufacturers' recommended firing temperatures. Mulla and Weiner [14] indicated that blue was the most unstable stain, while orange demonstrated the greatest color stability at higher firing temperatures.

With regard to the substrate, the metal substructure may influence ceramic color change in metal ceramic restorations. A lower L* value lowers the luminosity. In the metal ceramic groups, L* coordinate means were smaller than those in the zirconia groups. These results could be due to the presence of a metal substructure, which interferes with the optical properties of the material, thus reducing its translucency [47].

Related to the ceramic veneering techniques, it was observed that pressed groups for both ceramic systems (PZI and PMI) were more color stable than the layered groups (LZI and LMI) and it may be attributed to the increased number of firing cycles for which the layering groups expose this in agreement with other studies that reported, the layering group demonstrated a shade difference well below the clinically acceptable limit. Although the shade difference between the shade tab and the pressing group was within a clinically acceptable range, the pressing group demonstrated markedly higher (C) and (b) values. This can be explained by the highly saturated monochromatic nature of the ceramic ingots produced for the pressing veneering technique [52-54].

The limitations of this study include that it was conducted with a limited one shade and a fixed thickness for all ceramic types; further studies are needed for including more variables related shade effects.

Conclusions

Within the limitations of this *in vitro* study, the following conclusions were drawn:

1. Repeated firings caused a perceivable but acceptable color differences for all tested ceramic types.
2. The least color changes were observed with the IPS InLine POM and IPS e-max Zirpress groups.
3. The metal substructure may influence ceramic color change in metal ceramic restorations.

Acknowledgments

Our sincere thanks go to D ahmed saleem, for his great cooperation and help in the fabrication of the specimens.

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Volume 6 Issue 3 December 2016
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