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The comparative evaluation of the color stability of two ceramic systems with varying thickness and frequency of firing: an invitro study

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Abstract

Introduction : Color matching between ceramic restorations has become a major challenge in dentistry. Usually completed restorations do not match the shade guide , as esthetics of many ceramics gets affected by translucency . Ceramic translucency can be affected by many factors , including thickness , microstructures and the number of firing cycles. Failure in achieving appropriate shade of the prosthesis may result in great esthetic inconvenience for both the patient as well as the clinician.

Aim : To evaluate the color stability of two Ceramic systems Aluminium oxide and Zirconium oxide and to study the effect of ceramic thickness (0.5mm , 1mm , 1.5mm) and number of firings (3,5,7) on the color stability of Aluminium oxide and Zirconium oxide Ceramic systems.

Materials and methods: 21 disc shaped specimens 10mm in diameter and 0.6mm core thickness are made from Aluminium oxide Ceramic systems as well as Zirconium oxide (4mm diameter and 10mm core thickness). These two Ceramic systems are divided into 3 groups (n=7) veneering with dentin ceramic thicknesses as 0.5,1,1.5mm . Repeated firing (3,5,7) are performed and color of the specimens is compared with the color after the initial firing. Color differences among Ceramic specimens are measured using a spectrophotometer (SpectroshadeTM micro-MHT s.p.a) and data expressed in CIE lab system coordinates.

Results: Increase in Ceramic thickness resulted reduction in L* values and increase in a* and b* values for both Aluminium oxide and Zirconium oxide. Increase in number of firings resulted decrease in L* values making the specimen darker. Increase in a* and b* values making the specimens redder and yellower in Chroma.

Discussion: This invitro study measured the color changes of ceramic specimens prepared at different thicknesses (0.5, 1, 1.5mm) and fired at 3, 5, 7 times. The results of this study support the hypothesis that color differences would be noted relative to firing times and dentin ceramic thicknesses. There were significant differences in color changes within groups. In the current study, the specimens had ceramic thicknesses of 0.5, 1, or 1.5 mm, with a core thickness of 0.6 mm for Aluminium oxide and 1mm for Zirconium oxide.

Conclusion: Lab values of Aluminium oxide and Zirconium oxide were affected by number of firings and Ceramic thicknesses . Lab values of Aluminium oxide and Zirconium oxide were affected by number of firings and Ceramic thicknesses.

Keywords: Ceramics, Firings, Thickness, Color stability, Spectrophotometer.

Introduction

Ceramics have been widely used in dentistry because of their ability to provide excellent cosmetic results that mimic natural teeth. They are biocompatible, allow adequate reflection and transmission of light, and they exhibit good mechanical strength when subjected to masticatory efforts. In the search for a material to replace the metal infrastructure of a metalloceramic prosthesis also characterized with aesthetic excellence. McLean and Hughes introduced Aluminium oxide (Al_2O_3) as a reinforcing phase in dental porcelain in 1965. The incorporation of strengthening components to the feldspathic glass matrix enabled the construction of Ceramic infrastructures without the presence of metal, initiating an era of advances in the development of new Ceramic systems and processes routinely used in current dental offices. The first Ceramic infrastructures made of Alumina were obtained by a process known as craft Ceramic infiltrating slipcasting, where an infrastructure of high-density crystal is prepared with a small amount of glass. With the advent of CAD/CAM processing technology, all Ceramic prostheses could be fabricated with an infrastructure of pure Aluminium oxide (99.5%). The powder is packaged on a die in refractory Ceramic process known as vacuum uniaxial pressing. [1]

Since the introduction of Aluminium oxide- reinforced feldspathic porcelain, new materials for all-Ceramic restorations are made available. The one material currently of great interest is Zirconium. Zirconia has emerged as a versatile and promising material because of its biological, mechanical and optical properties, which has certainly accelerated its routine use in CAD/CAM technology for different types of prosthetic treatment. Yttrium-stabilized tetragonal Zirconium (Y-TZP) is currently used as a core material in all-Ceramic dental restorations. Although there are currently several types of Ceramic systems based on Zirconia, the 3Y-TZP is the most studied and used in dentistry. The 3Y-TZP consists of an array of partially stabilized Zirconia with a 2% 4mol yttrium oxide, as yttrium oxide is suitable for optical applications due to its high refractive index, low absorption coefficient and high opacity in the visible and infrared spectrum. Recently, in order to produce Ceramic blocks with greater durability and stability under high temperatures and humid environments, the industry has introduced small amounts of Alumina to 3Y-TZP, constituting a variation called TZP-A. This combination has shown to produce substantial improvements in fracture toughness, strength and thermal shock resistance. However, other properties, such as translucency and fusion temperature, are adversely affected [2].

In addition to new framework materials, veneering porcelains are being engineered with fine microstructures to improve the clinical benefits for the patient. Concomitantly, the microstructures create improved optical properties that more closely mimic the properties of natural teeth. Instrumental measurements can quantify color and allow communication to be more uniform and precise. Colorimeters and Spectrophotometers calculate the tooth color by measuring the amount and spectral composition of light reflected on the surface of the tooth. They usually express the results in the CIELab system, as well as in one or more of the conventional shade guide systems. The understanding of color science relative to teeth has improved in recent years. Spectrophotometers measure the reflectance or transmittance factors of an object one wavelength at a time. They have been used to measure the spectral reflectance curves of porcelains and extracted teeth[3].

In assessing chromatic differences, 2 color systems are used. Munsell color system and Standard Commission Internationale de L'Eclairage (CIELab) color system. The CIELab system is one of the standard color models used to describe all visible colors, using 3 basic coordinates[4].

L coordinate is a measure of the lightness-darkness of the specimen. a coordinate is a measure of the chroma along the red-green axis. b coordinate is a measure of chroma along the yellow-blue axis. The greater the L* the lighter the specimen. Positive a* coordinate relates to the amount of redness. Negative a* relates to a greenness of a specimen. Positive b* coordinate relates to the amount of yellowness. Negative b* relates to the blueness of the specimen. ΔL* , Δa* , Δb* represents the difference in CIE color space parameters of the two colors. The total color differences were calculated with the following equation.

$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ [5]

Ceramists or manufacturers contend that porcelain manipulative variables cause shade variability. Several factors that affect the ability of a Ceramic system to produce an acceptable match with corresponding shade guides , such as condensation techniques, firing temperatures, and dentin thickness have been investigated[5].

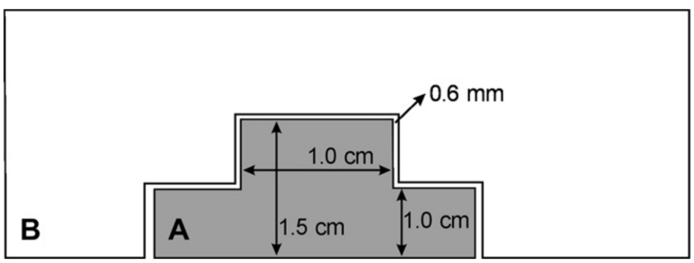
Hue and value color parameters of metal-ceramic specimens, which were fired 1.6°C and 21°C above the manufacturer's recommended firing temperature, indicated substantial differences[4]. A spectrophotometric analysis[3] determined variations in optical characteristics of porcelains produced by different manufacturers which add to the problem of color control in Ceramic crown fabrication. In visual studies of multiple firing of porcelain, color changes were not reported[6]. Translucency of Zirconia copings[7] were evaluated which were made with different CAD/CAM systems. The study demonstrated that all ZrO_2 copings made by Lava showed highest level of light transmission. O'Brien et al[8] determined perceivable differences (ΔE=1) between the color of Ceramic specimens that were fired 3 and 6 times. However, other studies determined that the number of firings (3,5,7) and dentin Ceramic thickness (0.5,1,1.5mm) have a definite effect on the final color of Aluminium oxide[5,35] and Zirconium oxide[26,37] all Ceramic systems tested.

None of the studies compared Aluminium oxide system with that of Zirconia. Since the literature is sparse related to the studies mentioned, it was decided to take up this study. Wherein, we compared the effects of repeated firings (3, 5, and 7) and dentin Ceramic thicknesses (0.5mm, 1mm, 1.5mm) on the color stabilities of Aluminium oxide and Zirconia system.

Materials and methods

Twenty one disc shaped specimens 10mm in diameter and 0.6mm core thickness are made from Aluminium oxide (Noritake, dental supply co ltd, Japan) Ceramic systems as well as Zirconium oxide (4mm diameter and 10mm core thickness) (IPS emax ZirCAD , Ivoclor Vivadent, schaan,Liechenstein). These two Ceramic systems are veneered with dentin ceramic thicknesses 0.5 ,1 ,1.5mm. For Aluminium oxide Noritake and Nano-fluoroapatite (IPS e-max ceram) for Zirconium oxide is used as corresponding veneer ceramic. Repeated firings (3,5,7) are performed and color of the specimens is compared with the color after the initial firing. Color differences among Ceramic specimens are measured using a Spectrophotometer (spectroshade TM micro-MHT s.p.a) and data expressed in CIE lab system coordinates.

A metal master model was machined to fabricate twenty one Aluminium-oxide core specimens each 0.6mm in thickness and 10mm in diameter.



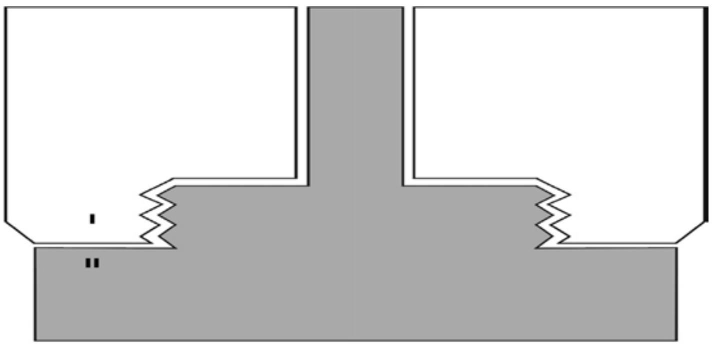
Mold used to standardize core thickness of Aluminium oxide specimens. **A,** metal index for preparation of Aluminium oxide core material. **B,** metal index for standardization of thickness of core material.

The metal master model consists of 2 parts . Part A, which is used to prepare the Aluminium oxide core material and Part B, which is used to standardize the thickness of core material. Between Part A and Part B a space of 0.6mm is present which standardizes the core thickness. The metal master molds (Part A & Part B) were boxed with modeling wax to required height over a glass slab. Wirosil® duplicating silicone was mixed and filled according to the manufacturer's instructions. Then it was allowed to harden in air for 30 minutes as per the recommended setting time. The wax was then removed and the metal master molds were separated from the duplicating form.

Wirosil® duplicating mould was then sprayed with Aurofilm preparation liquid, and was carefully blow dried. 18ml BegoForm® liquid and 100 gms of BegoForm® were added in the mixing bowl. BegoForm® and liquid were mixed initially over the vibrator, then manually using a spatula for 2 minutes. The mixed BegoForm® was poured in the Wirosil® duplicating mould to harden in air for 45-60 minutes as per the manufacturer's recommendations. Then, the Refractory molds were removed from the Wirosil® duplicating mould.

The retrieved refractory molds were then kept for oxidation for 6 hours at 1150°C. The oxidation (Degassing) program was conducted for the refractory molds in a Burnout Furnace starting from 500°C standby temperature and 1150°C final temperature with a 10°C increase in temperature per minute, and then was held at the final temperature for 1 hour. The refractory molds were later left for cooling at room temperature.

The refractory molds were soaked before each operation. Excess liquid was dabbed using a cellulose cloth. A fine grained (2-5µm) Aluminium oxide (Noritake) slip was brushed on Part B of Refractory molds, then Part A of refractory mold was kept over Part B to standardize the core thickness to 0.6mm . Once the standardized core thickness was achieved, part B was then kept in a furnace (VOP Dentmaster 80J) and fired at 950°C for 50 minutes. After firing, the refractory molds were left for cooling at room temperature for 20 minutes . After the firing, refractory molds were blastout with the help of the precision blaster (EasyBlast) using Perlablast® micro at a pressure of upto 2 bars. In the similar manner all the 21 core samples were prepared.



Apparatus used to standardize dentin ceramic thickness .**I**, First piece of mold with 10-mm cylindrical cavity in middle; II, second piece of mold with piston system that moves up and down in cavity when piece is turned.

A custom-made stainless steel mold was used to prepare standardized dentin thicknesses. The mold was prepared in 2 pieces. The first piece (I) had a 10-mm-diameter cylindrical cavity in the middle. The second piece (II) 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 upper surface of the apparatus was divided into 20 equal units. When it was calibrated, the piston moved downward with a sensitivity of 0.5 mm with 1 unit turn of the lower piece. The piston descended 1.0 mm with 2 turns of the screwed lower piece. The required ceramic thickness was provided by adjusting the depth of the cavity above the piston by turning the screwed lower piece the necessary amount. Later, the cavity was filled with Ceramic material, and the thickness of the Ceramic to be transferred to the core was adjusted in the same manner. With the help of the above mentioned procedure Conventional veneering ceramic (Noritake A1) was applied on the glass-infiltrated cores with thicknesses of 0.5, 1, and 1.5 mm by turning the lower piece of the apparatus 1 turn for 0.5mm, 2 turns for 1mm and 3 turns for 1.5mm thickness of veneering layers . Then, each of the specimen was fired at 940°C for 25 minutes as per the manufacturers instructions. Repeated firings were performed for each specimen with initial firing after application of core, dentin and enamel (with thickness of 0.5mm, 1mm, 1.5mm) completing 3 firings. Later, proceeding with the 4^{th} ,5^{th} ,6^{th} , and 7^{th} firings without the further application of ceramic. Then, the color parameters were recorded for each specimen at 3^{rd} firing, 5^{th} firing and 7^{th} firing.

Cylindrical blocks , 4 mm in diameter, were obtained by milling presintered zirconia blocks (IPS e-max ZirCAD) after scanning a metal disc of the required dimension (Fig.30). The milled Zirconia core discs were sintered at 1500°C for 2hours according to the manufacturer's recommendations (IVOCLOR VIVADENT). Twenty one Zirconium-oxide core specimens with a thickness of 1 mm were fabricated by cutting milled cylindrical blocks with a lowspeed sintered diamond disc (Gebr Brasseler GmbH, Lemgo, Germany) under water irrigation. The Zirconium oxide core specimens were prepared for the application and firing of the veneering layers with nano-fluoroapatite ceramic (IPS e-max ceram, Ivoclor Vivadent) by application of Z-liner (IPS e-max, Ivoclor Vivadent) and firing at 960°C for 10 minutes.

A custom-made mold with a 4mm diameter cylindrical cavity in the middle was used to prepare standardized dentin thicknesses as mentioned above for the fabrication of Aluminium-oxide specimens. The required ceramic thickness was provided by adjusting the depth of the cavity above the piston by turning the screwed lower piece the necessary amount. Then, the disk was placed in the cavity and the corresponding veneering ceramic slurry (Nano-fluorapatite ,IPS e-max Ceram; Ivoclor Vivadent), shade A1, was condensed with vibration on the core disc to a predetermined thicknesses of 0.5, 1, or 1.5 mm. Excess moisture was removed with paper tissue to minimize porosity, and firings were performed in a dental furnace (VOP ceramic master) at 950°c for 16 minutes (Fig 37). The thickness of each group of specimens was then measured with a micrometer (Renfert GmbH, Hilzingen, Germany) with an accuracy of 0.05 mm, and corrected with diamond rotary cutting instruments until the desired thickness of dentin ceramic was achieved (0.5, 1, or 1.5 mm). Repeated firings were performed for each specimen with initial firing after application of Z-liner, dentin and enamel (with thickness of 0.5mm, 1mm, 1.5mm) completing 3 firings. Later, proceeding with the 4^{th}, 5^{th}, 6^{th}, and 7^{th} firings without the further application of ceramic. Then, the color parameters were recorded for each specimen at 3^{rd} firing, 5^{th} firing and 7^{th} firing.

The color of each specimen was measured with a Spectrophotometer (spectroshade™ Micro-MHT s.p.a) . This instrument measures the spectral reflectance of a color and converts it into a tristimulus value, or internationally accepted numerical form. The Spectrophotometer's CIELab output is based on D65 illuminant and a 2-degree standard observer. Three measurements were made, and the average reading was calculated for each specimen. Instrument calibration was evaluated after measurement of each group (n=7) and recalibrated. The CIELab system is one of the standard color models used to describe all visible colors, using 3 basic coordinates.

The total color differences were calculated with the following equation.

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

ΔL^*, Δa^*, Δb^* represents the difference in CIE color space parameters of the two colors. Three measurements were made using Spectroshade . The average of 3 readings were taken for all samples (Aluminium oxide, Zirconium oxide). The readings were statistically analyzed to arrive at a conclusion.

Results

This in-vitro study was designed to study the effect of the number of firings and dentin ceramic thickness on the color of two commercially available ceramic systems -Aluminium oxide and Zirconium oxide. Both the ceramic systems (n=7) were divided into three subgroups based on the veneer thicknesses (0.5, 1, 1.5mm). All the specimens were fired (3, 5, and 7) in a ceramic furnace and the color parameters were recorded using a Spectrophotometer (Spectroshade™ Micro, MHT s.p.a). A comparative study consisting of twenty one disc shaped specimens each for both ceramic systems -Aluminium oxide and Zirconium oxide, divided into seven main groups. For Aluminium oxide & Zirconium oxide, each of these seven main groups are further divided into three subgroups based on the ceramic thickness (0.5mm, 1mm , 1.5mm) :

Subgroups	Aluminium oxide	Zirconium oxide
Subgroup I	$Al^{n}_{0.5}$	$Zr^{n}_{0.5}$
Subgroup II	Al^{n}_{1}	Zr^{n}_{1}
Subgroup III	$Al^{n}_{1.5}$	$Zr^{n}_{1.5}$

The comparative evaluation of ΔL, Δa, Δb and ΔE in 3^{rd} firing, 5^{th} firing and 7^{th} firing for 0.5mm, 1mm and 1.5mm for Aluminium oxide ceramic system was done. The difference in mean ΔL, Δa, Δb, ΔE values between the 3rd firing, 5th firing, 7th firing at 0.5mm thickness were found to be statistically significant (P<0.001). The difference in mean ΔL, Δa, Δb, ΔE values between the 3rd firing, 5th firing, 7th firing at 1mm thickness were found to be statistically significant (P<0.001). The difference in mean ΔL, Δa, Δb, ΔE values between the 3rd firing, 5th firing, 7th firing at 1.5mm thickness were found to be statistically significant (P<0.001) (table 4).

The comparative evaluation of ΔL ,Δa, Δb and ΔE in 3rd firing, 5th firing and 7th firing for 0.5mm ,1mm and 1.5mm for Zirconium oxide ceramic system was done. The difference in mean ΔL, Δa, Δb, ΔE values between the 3rd firing, 5th firing, 7th firing at 0.5mm thickness were found to be statistically significant (P<0.001). The difference in mean ΔL, Δa, Δb, ΔE values between the 3rd firing, 5th firing, 7th firing at 1mm thickness were found to be statistically significant (P<0.001). The difference in mean ΔL, Δa, Δb, ΔE values between the 3rd firing, 5th firing, 7th firing at 1.5mm thickness were found to be statistically significant (P<0.001). Since there was a significant difference, multiple comparisons (post hoc-test) using Bonferroni method was carried out to find out among which pair or groups there exist a significant difference. (Table 5).

The Pair wise (post –hoc Tukey test) Comparative evaluation of ΔL, Δa, Δb and ΔE in 3rd firing, 5th firing and 7th firing for 0.5mm, 1mm and 1.5mm for Aluminum Oxide Ceramic system was done. The difference in mean ΔL, Δa, ΔE values at 0.5mm, 1mm, 1.5mm thicknesses were found to be statistically significant between 3rd -5th firing (P<0.001), 3rd -7th firing (P<0.001) as well as 5th -7th firing (P<0.001) . Whereas, the difference in mean Δb values at 0.5mm, 1mm thicknesses were found to be statistically significant between 3rd -5th firing and 3rd -7th firing (P<0.001) as well as 5th -7th firing (P<0.05) (Table 6).

The Pair wise (post –hoc Tukey test) Comparative evaluation of ΔL, Δa, Δb and ΔE in 3rd firing, 5th firing and 7th firing for 0.5mm, 1mm and 1.5mm for Zirconium Oxide ceramic system.

It was found that the difference in mean ΔL values at 0.5mm thickness, Δa and ΔE values at 0.5mm, 1mm, 1.5mm, Δb at 0.5mm and 1.5mm was found to be statistically significant between 3rd-5th firing (P<0.001), 3rd-7th firing (P<0.001) as well as 5th-7th firing (P<0.001) . Whereas, the difference in mean ΔL values at 1mm and 1.5mm thicknesses were found to be statistically significant between 3rd -5th firing (P<0.001), 3rd -7th firing (P<0.001) , not statistically significant at 5th -7th firing (P>0.05) . The difference in mean Δb values at 0.5mm and 1.5mm thickness was found to be statistically significant between 3rd -5th firing (P<0.001), 3rd -7th firing (P<0.001) as well as 5th -7th firing (P<0.001) . Whereas, the difference in mean Δb values at 1mm thickness was found to be statistically significant between 5th -7th firing (P<0.05).

From the factorial ANOVA (**Table 8**) its determined that there is a significant difference present in the color parameters ΔL, Δa, Δb with the no. of firings (3,5,7) (P<.001), ceramic systems -Aluminium oxide and Zirconium oxide (P<.001) , thickness (0.5,1,1.5mm) (P<.001). There is significant difference present in the color parameters ΔL, Δa, Δb with the combined effect of no. of firings and ceramic thickness (P<.001), ceramic thickness and ceramic systems (P<.001), no. of firings and ceramic systems (P<.001) , ceramic thickness , no of firings and ceramic systems (P<.001).

In order to find out effect of the interaction of the ceramic thicknesses and the firings on the color parameters of the ceramic systems there exists a significant difference; we carried out multiple comparisons (3*2*3 GLM). The results are given in **Tables 9 to Table 11.** Through multiple comparisons in **Table 9** , we observe that the mean difference are statistically significant for ΔL color parameter for Zirconium oxide between 0.5mm-1mm, 1mm-1.5mm, 0.5mm-1.5mm at 3rd , 5th, 7th firings (P<.001). Wherein the mean difference are not statistically significant for all thicknesses 0.5mm-1mm, 1mm-1.5mm, 0.5mm-1.5mm at 5th and 7th firing (P>0.05) for Aluminium oxide. The Aluminium oxide samples show moderately significant values between the thicknesses 0.5mm-1.5mm and 1mm-1.5mm for the 3rd firing (P<0.05).

Table 10 showed the results of multiple comparisons of different thicknesses at different firings for the two ceramic systems and their effect on the color parameter Δa. We observe that no significant variation is present between the thicknesses 1mm-1.5mm for Aluminium oxide at the 3rd and the 5th firing (P>0.005). At all other thicknesses and firings (3rd, 5th , 7th) for both ceramic systems there is statistically significant variation present (P<0.001).

Table 11 showed the results of multiple comparisons of different thicknesses at different firings for two different ceramic systems and their effect on the color parameter Δb. We observed that no significant variation present between the thicknesses 0.5mm-1.5mm for Aluminium oxide at the 3rd and the 7th firing (P>0.05). Whereas moderately significant variations are present for between the thicknesses 0.5mm-1mm and 0.5mm-1.5mm for Zirconium oxide at the 5th firing (P<0.05). And no significant variation was present between the thicknesses 1mm and 1.5mm at the 5th firing for Zirconium oxide (P> 0.05). Between the other thicknesses for Aluminium oxide and Zirconium oxide at the different firings strongly significant variation was present (P<0.01).

Table 4: Comparative evaluation of ΔL, Δa, Δb and ΔE in 3rd firing, 5th firing and 7th firing for 0.5mm, 1mm and 1.5mm for Aluminum Oxide ceramic system

	thickness	3rd firing	5th firing	7th firing	P value
ΔL	0.5mm	5.21±0.33	4.19±0.2	3.27±0.08	<0.001**
	1mm	5.24±0.22	4.04±0.11	3.31±0.11	<0.001**
	1.5mm	5.34±0.21	4.14±0.05	2.61±0.12	<0.001**
Δa	0.5mm	-0.59±0.07	0.26±0.05	1.31±0.04	<0.001**
	1mm	0.23±0.11	1.5±0.08	2.13±0.14	<0.001**
	1.5mm	0.27±0.05	1.47±0.05	2.30±0.08	<0.001**
Δb	0.5mm	2.87±0.24	3.24±0.05	3.60±0.08	<0.001**
	1mm	1.56±0.14	2.36±0.08	2.54±0.10	<0.001**
	1.5mm	2.69±0.23	3.21±0.11	3.66±0.08	<0.001**
ΔE	0.5mm	5.96±0.28	5.27±0.15	4.99±0.09	<0.001**
	1mm	5.47±0.20	4.87±0.10	4.64±0.16	<0.001**

	1.5mm	5.96±0.13	5.43±0.05	5.00±0.15	<0.001**

Table 5: Comparative evaluation of ΔL, Δa, Δb and ΔE in 3rd firing, 5th firing and 7th firing for 0.5mm, 1mm and 1.5mm for Zirconium oxide ceramic system

	thickness	3rd firing	5th firing	7th firing	P value
ΔL	0.5mm	5.63±0.08	4.27±0.08	3.56±0.08	<0.001**
	1mm	4.51±0.11	3.26±0.14	3.19±0.09	<0.001**
	1.5mm	0.39±0.07	0.16±0.05	0.14±0.05	<0.001**
Δa	0.5mm	-3.67±0.08	-2.33±0.14	-1.41±0.11	<0.001**
	1mm	-2.46±0.18	-1.27±0.05	0.64±0.05	<0.001**
	1.5mm	-2.77±0.14	-1.54±0.13	1.13±0.05	<0.001**
Δb	0.5mm	-2.53±0.05	-1.16±0.1	0.71±0.09	<0.001**
	1mm	-2.11±0.16	-1.20±0.06	1.13±0.08	<0.001**
	1.5mm	-1.54±0.05	-1.19±0.07	1.21±0.07	<0.001**
ΔE	0.5mm	7.17±0.08	4.91±0.16	3.87±0.05	<0.001**
	1mm	5.57±0.10	3.66±0.14	3.40±0.10	<0.001**
	1.5mm	3.20±0.12	1.93±0.13	1.63±0.08	<0.001**

Table 6: Pair wise Comparative evaluation of ΔL, Δa, Δb and ΔE in 3rd firing, 5th firing and 7th firing for 0.5mm, 1mm and 1.5mm for Aluminum Oxide ceramic system.

	thickness	Difference			P value		
		3rd firing-5th firing	3rd firing-7th firing	5th firing-7th firing	3rd firing-5th firing	3rd firing-7th firing	5th firing-7th firing
ΔL	0.5mm	1.03	1.94	0.91	<0.001**	<0.001**	<0.001**
	1mm	1.20	1.93	0.73	<0.001**	<0.001**	<0.001**
	1.5mm	1.20	2.72	1.53	<0.001**	<0.001**	<0.001**
Δa	0.5mm	0.84	1.90	1.06	<0.001**	<0.001**	<0.001**
	1mm	1.27	1.90	0.93	<0.001**	<0.001**	<0.001**
	1.5mm	1.20	2.02	0.83	<0.001**	<0.001**	<0.001**
Δb	0.5mm	0.37	0.73	0.36	<0.001**	<0.001**	<0.001**
	1mm	0.80	0.99	0.19	<0.001**	<0.001**	0.013*

	1.5mm	0.53	0.97	0.44	<0.001**	<0.001**	<0.001**
ΔE	0.5mm	0.69	0.97	0.29	<0.001**	<0.001**	0.031*
	1mm	0.60	0.83	0.23	<0.001**	<0.001**	0.036*
	1.5mm	0.53	0.96	0.43	<0.001**	<0.001**	<0.001**

Table 7: Pair wise Comparative evaluation of ΔL, Δa, Δb and ΔE in 3rd firing, 5th firing and 7th firing for 0.5mm, 1mm and 1.5mm for Zirconium oxide ceramic system

	thickness	Difference			P value		
		3rd firing-5th firing	3rd firing-7th firing	5th firing-7th firing	3rd firing-5th firing	3rd firing-7th firing	5th firing-7th firing
ΔL	0.5mm	1.36	2.07	0.71	<0.001**	<0.001**	<0.001**
	1mm	1.26	1.33	0.07	<0.001**	<0.001**	0.485
	1.5mm	0.23	0.24	0.01	<0.001**	<0.001**	0.894
Δa	0.5mm	1.34	2.26	0.91	<0.001**	<0.001**	<0.001**
	1mm	1.18	3.10	1.91	<0.001**	<0.001**	<0.001**
	1.5mm	1.23	3.90	2.67	<0.001**	<0.001**	<0.001**
Δb	0.5mm	1.37	3.24	1.87	<0.001**	<0.001**	<0.001**
	1mm	0.91	3.24	2.33	<0.001**	<0.001**	<0.001**
	1.5mm	0.36	2.76	2.40	<0.001**	<0.001**	<0.001**
ΔE	0.5mm	2.26	3.30	1.04	<0.001**	<0.001**	<0.001**
	1mm	1.91	2.17	0.26	<0.001**	<0.001**	0.001**
	1.5mm	1.27	1.57	0.30	<0.001**	<0.001**	<0.001**

Table 8: Repeated measures ANOVA results on Color change

Factors	ΔL		Δa		Δb		ΔE	
	F value	P value	F value	P value	F value	P value	F value	P value
Firings	180.5	<0.001**	132.9	<0.001**	54.314	<0.001**	87.32	<0.001**
Ceramic brand	339.8	<0.001**	198.2	<0.001**	521.4	<0.001**	168.71	<0.001**
Thickness	575.9	<0.001**	341.5	<0.001**	134.5	<0.001**	455.3	<0.001**
Firing*Thickness	4.758	0.002**	13.71	<0.001**	7.218	<0.001**	14.92	<0.001**
Oxide*Thickness	479.31	<0.001**	11.64	<0.001**	151.74	<0.001**	540.9	<0.001**

Table 9: Results of Multivariate analysis (3x2x3 GLM) on parameters ΔL

Firing	Ceremaic System	Comparison		Mean difference	SE	P value	95%CI	
		Thickness	Thickness				Lower	Upper
3	AluminumOxide	0.5 mm	1 mm	0.14	0.1	0.319	-0.08	0.35
		0.5 mm	1.5 mm	0.52	0.2	0.017*	0.08	0.97
		1 mm	1.5 mm	0.39	0.1	0.022*	0.05	0.73
3	Zirconium oxide	0.5 mm	1 mm	0.95	0.1	0.000**	0.73	1.16
		0.5 mm	1.5 mm	4.59	0.2	0.000**	4.14	5.04
		1 mm	1.5 mm	3.64	0.1	0.000**	3.3	3.98
5	Aluminum Oxide	0.5 mm	1 mm	0.17	0.1	0.149	-0.04	0.39
		0.5 mm	1.5 mm	0.05	0.2	0.992	-0.4	0.49
		1 mm	1.5 mm	-0.13	0.1	0.727	-0.47	0.21
5	Zirconium oxide	0.5 mm	1 mm	0.98	0.1	0.000**	0.77	1.2
		0.5 mm	1.5 mm	4.11	0.2	0.000**	3.67	4.56
		1 mm	1.5 mm	3.13	0.1	0.000**	2.79	3.47
7	Aluminum Oxide	0.5 mm	1 mm	-0.24	0.1	0.026	-0.46	-0.02
		0.5 mm	1.5 mm	0	0.2	1	-0.44	0.45
		1 mm	1.5 mm	0.24	0.1	0.228	-0.1	0.58
7	Zirconium oxide	0.5 mm	1 mm	0.57	0.1	0.000**	0.35	0.79
		0.5 mm	1.5 mm	4.07	0.2	0.000**	3.62	4.52
		1 mm	1.5 mm	3.5	0.1	0.000**	3.16	3.84

Table 10: Results of Multivariate analysis (3x2x3 GLM) on parameters Δa

Firing	Ceremaic System	Comparison		Mean difference	SE	P value	95%CI	
		Thickness	Thickness				Lower	Upper
3	Aluminum Oxide	0.5 mm	1 mm	-0.77	0.1	0.000**	-1.03	-0.51
		0.5 mm	1.5 mm	-0.68	0.14	0.000**	-1.03	-0.33
		1 mm	1.5 mm	0.09	0.06	0.405	-0.07	0.24
3	Zirconium oxide	0.5 mm	1 mm	-1.26	0.1	0.000**	-1.51	-1
		0.5 mm	1.5 mm	-1.07	0.14	0.000**	-1.42	-0.72
		1 mm	1.5 mm	0.18	0.06	0.015*	0.03	0.34
5	Aluminum Oxide	0.5 mm	1 mm	-0.91	0.1	0.000**	-1.16	-0.65
		0.5 mm	1.5 mm	-0.8	0.14	0.000**	-1.16	-0.45
		1 mm	1.5 mm	0.1	0.06	0.279	-0.05	0.26
5	Zirconium oxide	0.5 mm	1 mm	-1.39	0.1	0.000**	-1.65	-1.14
		0.5 mm	1.5 mm	-1.2	0.14	0.000**	-1.55	-0.84
		1 mm	1.5 mm	0.2	0.06	0.008**	0.04	0.35
7	Aluminum Oxide	0.5 mm	1 mm	-1.19	0.1	0.000**	-1.45	-0.94
		0.5 mm	1.5 mm	-1.57	0.14	0.000**	-1.92	-1.22
		1 mm	1.5 mm	-0.38	0.06	0.000**	-0.53	-0.22
7	Zirconium oxide	0.5 mm	1 mm	-1.68	0.1	0.000**	-1.94	-1.42
		0.5 mm	1.5 mm	-1.96	0.14	0.000**	-2.31	-1.61

		1 mm	1.5 mm	-0.28	0.06	0.000**	-0.43	-0.13

Table 11: Results of Multivariate analysis (3x2x3 GLM) on parameters Δb

Firing	Ceremaic System	Comparison		Mean difference	SE	P value	95%CI	
		Thickness	Thickness				Lower	Upper
3	Aluminum Oxide	0.5 mm	1 mm	1.12	0.08	0.000**	0.93	1.32
		0.5 mm	1.5 mm	-0.13	0.09	0.423	-0.36	0.1
		1 mm	1.5 mm	-1.25	0.06	0.000**	-1.4	-1.11
3	Zirconium oxide	0.5 mm	1 mm	-0.22	0.08	0.020**	-0.42	-0.03
		0.5 mm	1.5 mm	-0.67	0.09	0.000**	-0.9	-0.44
		1 mm	1.5 mm	-0.45	0.06	0.000**	-0.59	-0.3
5	Aluminum Oxide	0.5 mm	1 mm	1.14	0.08	0.000**	0.94	1.33
		0.5 mm	1.5 mm	0.3	0.09	0.008**	0.07	0.53
		1 mm	1.5 mm	-0.84	0.06	0.000**	-0.99	-0.69
5	Zirconium oxide	0.5 mm	1 mm	-0.21	0.08	0.031*	-0.4	-0.01
		0.5 mm	1.5 mm	-0.24	0.09	0.041*	-0.47	-0.01
		1 mm	1.5 mm	-0.03	0.06	0.937	-0.18	0.12
7	Aluminum Oxide	0.5 mm	1 mm	1	0.08	0.000**	0.8	1.19
		0.5 mm	1.5 mm	-0.01	0.09	0.999	-0.24	0.22
		1 mm	1.5 mm	-1	0.06	0.000**	-1.15	-0.86
7	Zirconium oxide	0.5 mm	1 mm	-0.35	0.08	0.000**	-0.55	-0.16
		0.5 mm	1.5 mm	-0.55	0.09	0.000**	-0.78	-0.32
		1 mm	1.5 mm	-0.2	0.06	0.006**	-0.34	-0.05

Graph 1

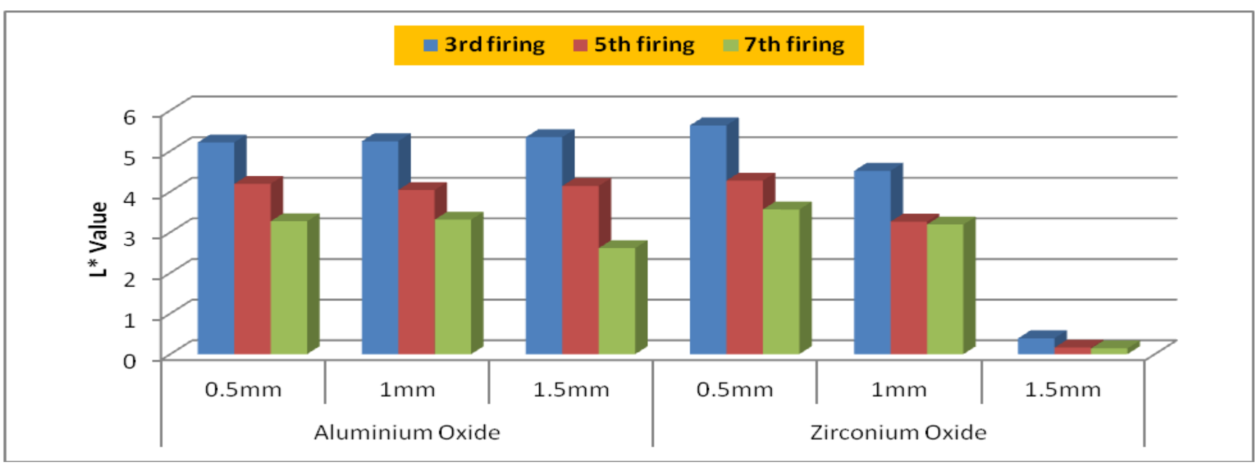


Fig 1: mean values of L* for different ceramic thicknesses and brand

Graph 2

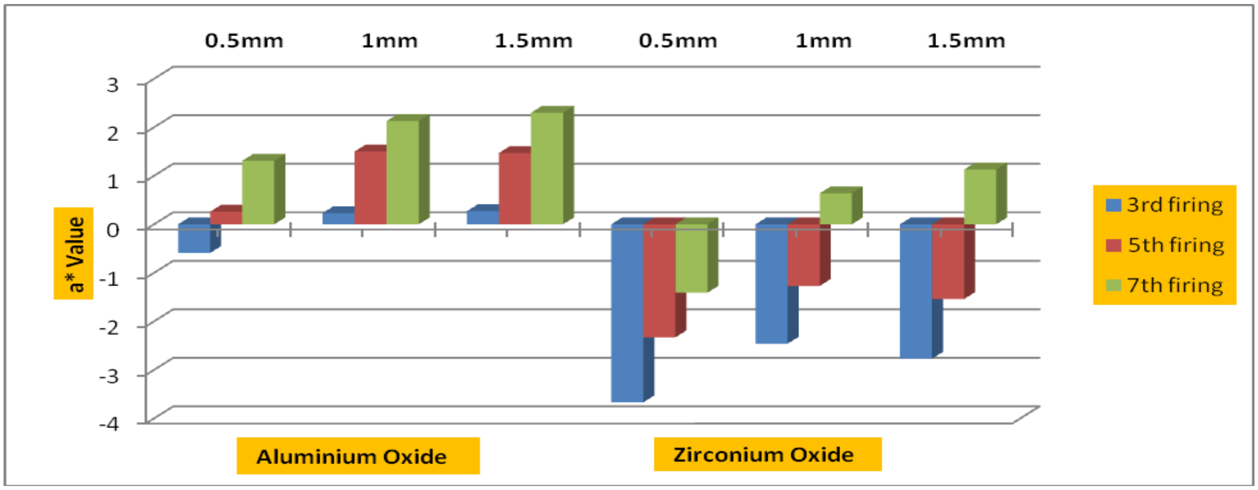


Fig 2: mean values of a* for different ceramic thicknesses and ceramic systems

Graph 3

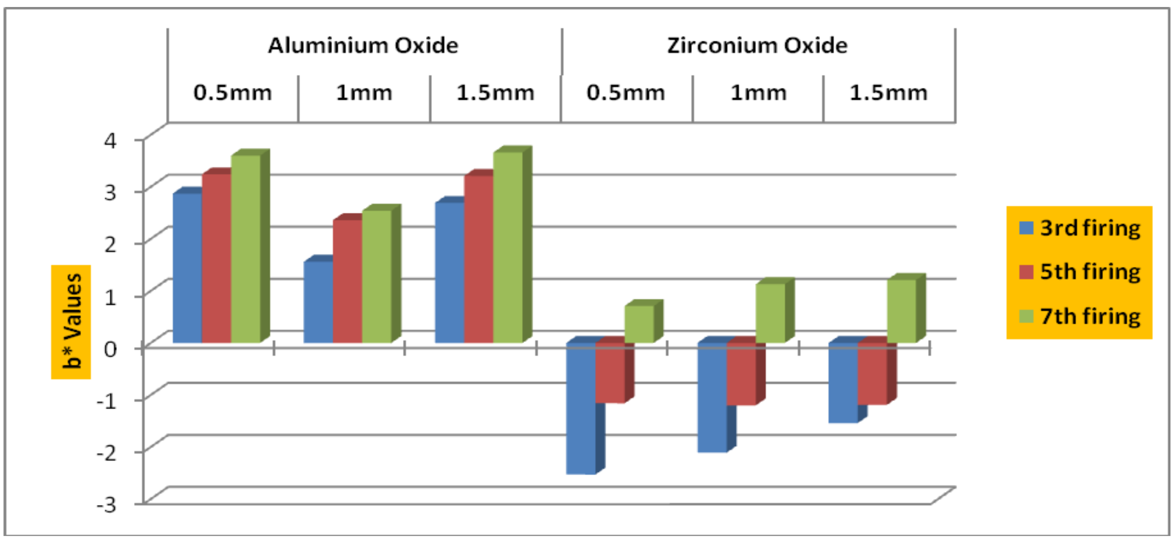


Fig 3: mean values of b* for different ceramic thicknesses and ceramic systems

Discussion

This invitro study measured the color changes of ceramic specimens prepared at different thicknesses (0.5, 1, 1.5mm) and fired at 3, 5, 7 times. The results of this study support the hypothesis that color differences would be noted relative to firing times and dentin ceramic thicknesses. There were significant differences in color changes within groups. Most all ceramic systems consist of a Ceramic core with a thickness of 0.5 to 1.0 mm and approximately 1.0 to 1.5 mm of space available for veneering ceramic. In the current study, the specimens had ceramic thicknesses of 0.5, 1, or 1.5 mm, with a core thickness of 0.6 mm for Aluminium oxide and 1mm for Zirconium oxide.

The L*a*b* values of Ceramic systems were affected by the Ceramic system (Aluminium oxide and Zirconium oxide), number of firings and the ceramic thickness. L* values, which reflect the brightness of the specimens, decreased for both systems as the total thickness of the specimens increased. There were significant increases in both a* and b* values as the dentin ceramic thickness increased. These changes in L*, a* and b* values are consistent with a study by Ozturk et al[26]. Antonson and Anusavice[12] studied the effect of change in the thickness of ceramics on the contrast ratio of dental core and veneering ceramic, and concluded that the contrast ratio was dependent on the type of the material tested. Heffernan et al[14] described the influence of core material thickness on its translucency and the influence of core plus ceramic veneer thickness on the overall translucency of specimens. Shokry et al[18] demonstrated that L* values decreased for leucite reinforced and spinell ceramics as the total thickness increased. The results of the present study are in agreement with the previous studies since the thickness of the layered ceramic influenced the final shade, partially due to the translucency, as the thicker Ceramic disks were less translucent.

In the current study, the color of specimens appeared darker, redder, and more yellow for both the systems. As the thickness of the body ceramic increased, the effect of diffuse reflection of the core ceramic diminished, and the majority of diffuse reflection occurred in the dentin layer. However, ΔE value among various thicknesses of ceramic in both systems was below the perceivable level (ΔE<1). Furthermore, these results demonstrated that there were visually undetectable color differences between the core and dentin ceramic.

Although some of the studies[6,10] have demonstrated the minimal effect of repeated firings on the color of body ceramic, O'Brien et al[8] reported that firing ceramic specimens up to 6 times resulted in perceptual color changes . In the current study, the interpretation of data achieved with a CIELAB system visually facilitated the comparison of the objective data with the subjective investigation. Conversely, statistically analyzed L*a*b* color parameters showed significant differences with repeated firings. An increase in the number of firings resulted in an appreciable decrease in L* values, which created darker specimens for both all-ceramic systems. It was observed that It was observed that a* and b* color values increased after repeated firings, resulting in specimens of ceramics that were redder and more yellow.

The mean ΔE values increased as the dentin ceramic thickness was increased. The ΔE value was smaller than 1 between firing 3 and 5, firing 5 and 7 and firing 3 and for all the Aluminium oxide samples. The ΔE value was higher than 1 between 3 and 5, 5 and 7, and 3 and 7 for all Zirconium oxide specimens. Color changes following repeated firings may also be attributed to the color stability of metal oxides during firing which can affect the resulting color of ceramic. Several studies have 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. Ceramic systems in the present study exhibited visual color changes during firing and demonstrated that changes in the thickness and repeated firings of ceramic have an effect on the final shade. Although significant differences were observed in L*a*b* parameters, the magnitude of mean color differences caused by various dentin thicknesses and repeated firings for both all-ceramic systems were at an acceptable perception level. Clinical success and color stability of ceramic restorations depend on laboratory and clinical variables. Ceramic systems in this study exhibited acceptable visual color changes. during firing conditions when the manufacturer's instructions were followed to ensure esthetically successful restorations. The results of this study suggest that dentin ceramic thickness and the number of firings of the all ceramic system tested significantly affect the final color of the all ceramic restorations. These are important factors for the definitive color of the restoration, and should be considered during shade selection and fabrication. Furthermore, the limitations of the study are, the study is limited to just two ceramic systems (Aluminium oxide and Zirconium oxide) and the specimens were disc shaped rather than shaped like crowns. The condensation technique, which could influence the reproducibility of the disc preparation, was shown to have no influence on the final shade of ceramics.[4,6] Therefore, the shades of sintered layered ceramic and those of assembled ceramic layers were considered equivalent. However, the effects of surface roughness and increase in pore volume on the light transmittance were difficult to control.

A future objective is to measure the effects of ceramic thickness and repeated firings of other new ceramic systems with different core thicknesses. Finally, all-ceramic restorations should be luted to the tooth substrate with a luting agent[10] whose shade and thickness contribute to the definitive appearance of ceramic restorations. Therefore, further study of the clinical implications of the color and translucency of consistent layers for all ceramic restorations, such as core and veneer ceramics, luting cements, and abutment, on the final shade of restorations after repeated firings, should be performed.

Conclusion

Within the limitations of this in-vitro study and based on the results of the statistical analysis, the following conclusions can be drawn: The L*a*b* values of ceramic systems were affected by the number of firings (3, 5, or 7), ceramic system (Aluminium oxide and Zirconium oxide) ($P<.001$), and ceramic thickness (0.5, 1, or 1.5 mm). An increase in the number of firings resulted in an appreciable decrease in L* value, which created darker specimens for both all-ceramic systems. The a* and b* color values increased after repeated firings, which resulted in ceramic specimens that were redder and more yellow in chroma. As the ceramic thickness increased, significant reductions in L* values and significant increases in both a* and b* values were recorded. This resulted in darker, redder and yellower specimens. The mean color differences caused by repeated firings were undetectable for Aluminium oxide specimens ($\Delta E<1$). However, for Zirconium oxide specimens, the mean ΔE value was higher than 1 for between 3 to 7 , 3 to 5 firings and 5 to 7 firings except for 1mm and 1.5mm specimens which are less than 1 between 5 to 7 firings .

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