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Original Article

Assessment of Color Difference of Translucent Zirconia Substructure Veneered Using a Layering Technique with Two Different Veneering Thicknesses: An *in-vitro* study

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ABSTRACT

***Background and objectives.** The introduction of zirconia to the dental field created a path for development of new designs and applications, but still, a minimum framework thickness of 0.5 mm with the remaining thickness of the restoration used for building the ceramic veneer was always recommended. This might have possibly affected the final shade of the restoration due to the whitish color of Y-TZP. This in vitro study was designed to assess the color difference of translucent zirconia substructure veneered using a traditional layering technique with two different veneering thicknesses. **Methods.** A total of twenty translucent Ice zirconia disc samples with standardized dimensions 12 mm in a diameter, 0.5mm in thickness were designed and constructed using zirkonzahn system. The samples were classified into two groups: Group I: (n = 10) veneered by 0.5 mm thickness layering technique using IPS emax Ceram dentin shade A2. Group II (n = 10) veneered by 1 mm thickness layering technique using IPS emax Ceram dentin shade A2. Twenty composite resin discs 12mm in diameter and 5mm in thickness in A3 shade, were fabricated to be bonded to ceramic specimens using Dual-curing translucent rely X Unicem automix Self-Adhesive Resin luting cement. Spectrophotometer was used to measure color parameters L*, a*, b* for all samples. ΔE values were measured to determine color differences between the specimens and the A2 VITA classical shade (target shade). ΔE values were compared with an acceptability threshold (ΔE=3.7). Independent t-test was used to analyze data (P<0.05) in this study and was analyzed using (SPSS) software, version 22. **Results**. The results showed that veneering thicknesses had a significant effect on the mean (ΔE) Values at P ≤ 0.001. The 0.5 mm veneer thickness showed the higher significant mean color difference (ΔE) than the 1.0 mm veneering thickness where the recorded mean (ΔE) Values were (4.15±1.31) (2.65±1.39) respectively at p ≤ 0.001. **Conclusions.** This study concluded that 1.0 mm veneer thickness was the optimum thickness regarding color matching.*

***Keywords**: Veneer Thickness, Zirconia, Veneering Technique, Color Difference, Spectrophotometer.*

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INTRODUCTION

The increased demand of dental client for natural looking restorations has resulted in development of metal-free ceramic system. The non-metallic substructure veneered with porcelain provided a deeper translucency close to natural tooth [1,2].

Recently, restorations with zirconia substructure have attracted attention. Compared to other materials used in full ceramic systems, zirconia is a highly superior material with its high rupture and bending strength properties, wearing resistance, and biocompatibility. However, zirconia substructure should be covered with a ceramic layer due to the disadvantage of its optical properties [3].

Veneering zirconia core can be done by three types of procedures: the traditional layering technique (veneered by condensing and sintering veneering porcelain), press-on technique (veneered by heat-pressing ceramic ingots), and CAD-ON technique [4,5].

The traditional layering technique represents the most common technique for veneering zirconia restorations sintered onto ceramic cores [6]. In traditional layered ceramic restoration final color occurs from a diffuse reflectance of the dentin porcelain layer filtered by the scattering of outer enamel porcelain layer [7]. So, optical scattering and absorption are affected by optical properties of veneering material thickness and reflectance of the core materials.

The esthetic value of dental ceramic restorations is influenced by several factors, thus, achieving the desired final color in these restorations is considered as a challenge. These factors include color, translucency, fluorescence, surface texture and shape [8,9,10]. Furthermore, the overall color of ceramic restorations can be influenced by the thickness of the ceramic, the thickness and the color of luting agent, and the color of the underlying tooth structure [10,11]. Many studies, they concluded that there was a significant correlation between the thickness core and the ceramic veneer to the color of the restoration [12,13,14]. O'Keefe et al [15], found that the thickness of a porcelain veneer was the primary factor affecting light transmission.

Color and translucency can be measured by using spectrophotometers [16]. The color difference (ΔE) can be determined by comparing the differences between respective coordinate values for each object [17].

Therefore, the specific aim of this in vitro study was to assess the color difference of translucent zirconia using two different veneering thicknesses.

METHODS

A total of twenty Zirconia (Translucent Ice zirconia zirkonzahn, Gais, Italy) disc samples with standardized dimensions (12mm diameter × 0.5mm thickness) were designed and constructed using zirkonzahn system Computer-Aided Design/computer -Aided Manufacturing (CAD/CAM) (Zirkonzahn Modellier 1.0b2 software). The samples were classified according to the thickness of the veneer layer into two groups: Group I: Ten samples (n = 10) zirconia core discs veneered by layering technique 0.5 mm thickness using IPS emax Ceram dentin (IvoclarVivadent, Schaan, Liechtenstein, Canada). Group II: Ten samples (n = 10) zirconia core discs veneered by layering technique 1 mm thickness using IPS emaxCeram dentin (IvoclarVivadent, Schaan, Liechtenstein, Canada).

Fabrication of zirconia disc samples

Translucent Zirconia ceramic discs (12 mm in a diameter, 0.5 mm in thickness), were constructed from Presintered translucent zirkonzahn blocks using the ZirkonZahn CAD/CAM system (Zirkonzhan, Steger, Ahrntal, Italy). In standardized manner using a specially designed cupper mold was machine-milled, the mold has 12 mm diameter cavity and 0.5 mm cavity depth.

The cupper master mold was sprayed with scanning spray (3D anti-glare spray, Germany) recommended by Zirkonzahn manufacturer, for antireflection in order to achieve optimal accuracy. The mold was then put in its place in the Zirkonzahn scanner (S600 ARTI, Gais, Italy for 3D scanning), scanning of the model was performed and the image was stored on the computer hard disk. Milling of zirconia block was run fully automated with a diamond stone bur 4L and stylus 4LA (cutting stone, Zirkon Zahn, Italy) under water cooling. Sintering of milled zirconia disc samples was done in a special sintering furnace (zirconfen 600). After complete sintering of the pre sintered zirconia discs, the discs were removed from the furnace. Dimensions of the samples were verified; using a digital caliper and then the samples were smoothened using grit silicon carbide papers under water irrigation.

Veneering of zirconia core discs

Twenty zirconia core discs were veneered using layering veneering technique IPS e.max Ceram dentine (IvoclarVivadent, Schaan, Liechtenstein, Canada) (shade A2) using the conventional layering technique at two different thicknesses which were (0.50 mm & 1mm). For veneer layer application, a specially designed two copper molds were machine milled in order to standardize the veneering thicknesses over the zirconia discs. Each mold consisted of two parts: an inner pistol part and an outer cupper ring. The molds were 12 mm diameter x 1.00 mm thickness & 12 mm diameter x 1.50 mm thickness.

A thin layer of separating medium (IPS Ceramic Separating liquid, IvoclarVivadent AG, Schaan, Liechtenstein) was applied on the walls of the molds by the aid of a painting brush. Zirconia discs were then placed inside the assembled mold. The IPS e.max Ceram Dentin A2 material was mixed with the build-up liquids all round by metal spatula on a glass slab. The wash firing of dentin material was brushed on the underlying zirconia substructure and performed at 750ºC. This ensures controlled shrinkage of the veneering material and homogenous bond to the zirconia substructure.

The veneering ceramic layer was built up with IPS e.max Ceram Dentin, by the help of the copper mold with 1mm cavity depth, the zirconia substructure 0.5 mm thickness was seated inside the mold, and the remaining part was built up in incrementally into the mold with the veneering ceramic material to create a full veneer thickness of 0.5 mm. The same veneering process was carried out for the 1mm veneering material thickness using the 1.5 mm cavity depth copper mold.

The mold was disassembled and fired in the furnace at 750ºC. Finishing was performed using finishing stones. The glaze firing cycle was started at 403°C for 6 minutes then raised without vacuum with heat rise rate of 60°C/min to 725°C and held for one minute. Samples were checked using magnifying lens at 5x magnification for detecting any defects, irregularities or cracks. Defective samples were discarded. Finally, samples thickness was measured by digital caliper and the finished samples were stored till testing.

Fabrication and cementation of composite discs

Twenty composite resin substrates in A3 shade, were fabricated according to manufacturer's instruction using a specially constructed cylindrical split Teflon mold. The mold has a circular central hole 12mm in diameter and 5mm in thickness. With an outer cupper ring that served for the assembling of the two halves of the Teflon mold. A thin layer of separating medium was applied on the Teflon mold that was seated on a clean dry glass slab. The composite material was inserted in two layers each1.5 mm, then the last 2.0-mm thick layer was applied, using a non-metallic instrument and topped with another glass slab to achieve optimum smoothness of composite resin. The resin composite was light activated for 40 seconds using a LED.D light curing unit (Miraj, LED.D curing light, Korea). The tip of light polymerizing unit was held at 1mm away from the sample. After completion of curing, the top glass slab and outer copper ring were removed, the Teflon mold was opened then the samples were further light cured for another 50 seconds.

The cemented side of zirconia discs were first airblasted with 50 μm aluminum oxide (Al2O3) particles at 1 bar pressure, from a distance of 10 mm for 5 seconds using an airborne- particle-abrasion device (Basic classic 25-70 μ - Renfert GmbH, Hilzigen, Germany). The abraded discs were then washed with tap water for 1 minute ultrasonically cleaned in a water bath for 10 minutes using ultrasonic device (Ney ULTTRA sonic, USA), then air dried. The cemented side of composite discs were manually finished using wet silicon carbide paper (Norton S.A., São Paulo, Brazil) (320,600 grit) then washed with tap water for 1 minute, and ultrasonically cleaned in distilled water for 10 minutes.

Cementation of zirconia discs and composite substrate was done using specially designed cementation device was machined from stain less steel in order to aid in load application. Cementation was accomplished according to the manufacture's instruction. Dual-curing translucent rely X Unicem automix Self-Adhesive Resin luting cement was used. Finishing of each cemented disc was made using finishing bur, till a flat surface was achieved necessary for color parameters measurement by allowing the contact tip of the spectrophotometer to contact the surface without any angulations. All disc samples were subjected to spectrophotometric analysis test. Shade tab A2 (Vitapan Classical, Vita) was selected as the required target color for all fabricated restorations. In order to flatten the measuring surface of the tab, a low-speed finishing stone was used to flatten the middle portion of labial surface of the tab.

Measurement of color

A computer Color-matching system (CCM) (UV-Shimadzu3101 PC- Spectrophotometer, Japan), was used for the spectrophotometric assessment of the specimens. The Color was assessed through the measurement of the diffuse reflectance. The L*, a* and b* values of the samples were recorded according to the CIELAB color scale relative to the standard illumination D65. The color for the middle portion of the A2 shade tab was measured. The color difference (ΔE) was calculated from the following equation [18].

$$\Delta E = [(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})] ½$$

Where, ΔE was the color difference between A2 shade tab and the measured disc sample, ΔL* refer to difference in lightness, Δa* and Δb* refer to difference in chromaticity values between the shade tab and the measured sample.

Statistical analysis

The independent t-test was performed to detect significance between groups. Statistical analysis was performed using SPSS IBM V.22. P values ≤0.05 are considered to be statistically significant difference between groups.

RESULTS

Data were presented as means and standard deviation (SD) values. The Independent t-test was used to analyze data in this study.

The result showed that layering veneering technique and thicknesses (0.5 mm & 1.0 mm) had a significant effect on mean (ΔE) Values at P ≤ 0.001.

Mean and standard deviation (SD) of the (ΔE) Values at different veneering thicknesses (0.5 mm &1 mm) were presented in table (1) and (fig.1).

The 0.5 mm veneering thickness showed higher statistical significance difference than the

1.0 mm veneering thickness where the recorded mean Color Difference (ΔE) Values were (4.15±1.31) (2.65±1.39) respectively at p ≤ 0.001.

Table 1: Mean and SD& results of statistical analysis for Color Difference ΔE) values of different zirconia veneer thicknesses. (0.5 mm &1 mm).

Thickness	0.5mm		1.0mm		P-Value
	Mean	SD	Mean	SD	
ΔE	4.15	1.31	2.65	1.39	≤ 0.001*

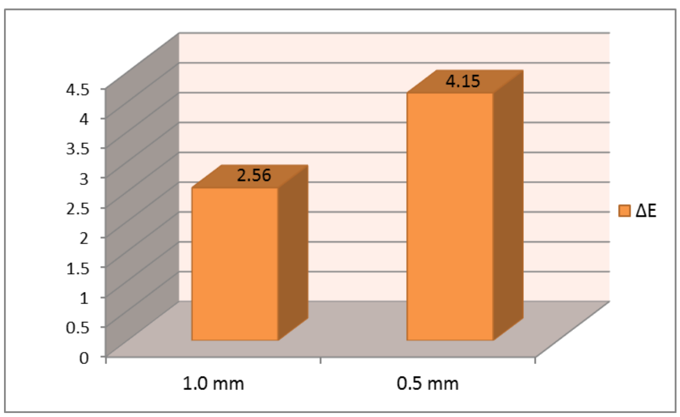

Figure 1. Histogram showing the mean ΔE values of different veneering thicknesses (0.5 mm &1mm).

DISCUSSION

The main challenge in esthetic dentistry is to optimally match the optical properties of restorative materials with the natural teeth [19].

The present study aimed to evaluate the effect of a traditional layering veneering techniques at different veneer thicknesses (0.5mm & 1 mm) on color difference of translucent ice zirconia substructure.

In this study the use of yttria partially stabilized tetragonal zirconia polycrystal Y-TZP zirconia substructure material was selected due to its superior mechanical properties as it is currently used as a core material in all ceramic dental restoration [20,21]. All samples of translucent zirconia substructure evaluated in the current study were prepared with the same thickness of 0.5 mm, as in the similar studies [7,22-25]. This thickness is sufficient for the use as a framework material in the bi-layered zirconia restorations.

For purpose of standardization, a specially constructed mold was constructed for the core samples as well as the core and veneer samples as used by different authors [22-25]. In the present study, zirconia core specimens were veneered with the traditional layering technique was selected as it is preferred by most clinicians due to its great optical properties and its ability to create depth notion and to nicely mimic tooth structure. Dentin porcelain for layering technique contains nano-fluorapatite crystals similar to those of vital teeth, which ensure the restorations match natural tooth accurately in terms of color, surface texture, and translucency [26,27]. IPS e.max Ceram used in the layering technique is characterized by a high stability of shape and shade, even after several firing cycles, and this permits a unique combination of translucency, brightness and opalescence [27]. IPS e.max Ceram A2 was used in case of layering technique compared with the shade tab A2 (target color) for all fabricated samples

Several authors [28-30] identified multiple factors, which affect the aesthetic such as material thickness, grain boundary, the content of the materials, color of the luting cement, zirconia grain size and sintering conditions.

Since the veneer thickness may vary depending on the available occlusal space and the level of anatomic characterization of the restoration, the different thicknesses of porcelain of layering veneering techniques used in the present study were 0.5 mm in thickness as recommended by the manufacturer, being the minimum veneering thickness over the 0.5 mm zirconia substructure thickness. While 1 mm is the typical thickness used in dental practice [31].

Amirhossein Fathi et al., 2019 [30] and Funda Bayindir et al., 2018 [17] who found that the repeated firings and porcelain veneer thickness affected the final color and translucency of both zirconia systems and, consequently, adversely influenced the esthetic outcomes.

The color and its parameters, such as hue, value, chroma, translucency, opacity, and fluorescence, influence the final esthetic of a dental restoration [32]. Changes of color and translucency may be expected when the thickness of porcelain layer changes, although the direction of color change may depend on the specific components of the ceramic systems [33].

Thus, the present study aimed to evaluate the effect of a traditional layering veneering techniques at different veneer thicknesses (0.5mm & 1 mm) on color difference of translucent ice zirconia substructure.

The influence of back ground substrate on the final appearance of the ceramic specimens is well established. in the present study Composite resin discs A3 in shade were fabricated to simulate dentin [34]. Natural colors such as white, grey and black are by definition, colors that have no hue. The white background was selected as a background to minimize the influence of background hue on the color measurement of the discs [35]. This arrangement allowed the investigation to focus on the effect of the veneer thickness on the disk color appearance.

Use of composite cements with the zirconia was capable of affecting a perceptible color difference [36,37]. Therefore, in this study, translucent self-

adhesive rely X Unicem cement was selected to bond the ceramic
disc with the composite substrate, and to exclude its effect on color measurement.

A flat surface was achieved after the finishing procedure, required for the measurement of the color parameters, to allow the contact tip of the spectrophotometer to contact the surface without any angulations [38].

In the present study, Vita pan classical shade guide (tab A2) was used for comparison, which has been used for years as a "standard'' for shades [36]. White silicone and grey rubber discs were also used to flatten and finish the middle portion of the labial surface of the Vita Pan classical shade tab A2 to allow more consistent color measurement (less coefficient of variation), as the translucency of the incisal edge and the cervical site may affect the color measurement. The metallic hand was also removed after polishing so as not to affect the color measurements [39].

In the present study, Spectrophotometer was used for color analysis. It represents one of the most accurate, useful and flexible instruments for overall color measuring in dentistry [40]. The commission international de 1'Eclairage (CIE) defined color space parameters that are generally used for instrumental color measurement: The CIE L* value represent the brightness of an object, or value on a numerical scale from 0 (black) to 100 (white). The CIE a* value is a measure of chroma in red green axis (a* positive=red & a*negative =green), and the CIE b* value is a measure of chroma in yellow blue axis (b*positive=yellow & b* negative =blue) [41]. For the evaluation of color match, the CIELab is used to determine the color difference between two objects. A single value, known as ΔE, is calculated from the formula: $\Delta E = [(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})]^{1/2}$, in order to measure the color difference [18]. Thereafter, the ΔE is compared with acceptability and perceptibility thresholds in order to evaluate the visibility of the color difference to human eyes.

Several studies tried to report acceptable ΔE limit but variations among these studies were noticed. Seghi et al., 1989, reported a color difference of ΔE = 2, on same way, [42] Ragain et al 2001, stated that the average CIE L*a*b* color difference for a match in the oral environment was (ΔE =3.7) [43]. Finally, Khashayar et al in 2014, explained in his review that more than half of the studies defined perceptibility thresholds as ΔE = 1, and acceptability threshold as ΔE = 3.7 being the threshold at which 50% of observers accepted the color difference [44]. The value reported in Khashayar study has been referenced for many years and so it was the reference for the present study.

The results of the present study for the samples of the 0.50 mm and 1.0 mm veneer thicknesses showed
statistical significance difference, where the mean ΔE value of the 0.50 mm veneer thickness was (ΔE= 4.15) which was considered above the clinically perceptible value (the highest significant) compared to the 1.0 mm veneer thickness.

These findings were in agreement with Shokry et al 2006 [12] and Turgut & Bagis 2013 [45] & Mahrouse A et al 2014 [46]. These could be explained by increased the overall chromatic components a*b* values approached those of the shade tab after veneering due to increase overall thickness of the samples

With regard to all-ceramic systems, L* value generally decreased due to increased absorption of incident light with thicker specimens, while a* and b* values increased as the ceramic thickness increased [12,13,47]. There might be a difference in the amount of light reflection at the opaque core between all-ceramic systems with different core translucency.

Also, Uludag B et al 2007 [48] and Son HJ et al 2010 [49] proved that L* value decreased as ceramic thickness increased, the decrease L* values which affect the color difference directly.

Previous studies have reported that increasing the ceramic thickness decreased the ceramic translucency and increased the ceramic masking ability. The present study confirmed the results of these studies [50-52]. The results were not in accordance with Bachhav & Aras 2011 [53] as it was stated that the mean ΔE values increased as the dentin ceramic thicknesses increased for zirconium oxide based all-ceramic specimens tested. Thus, could be explained by the fact that in their study they used different materials and thicknesses (zirconium oxide (LavaTM) substructure 1 mm thickness, veneered with dentin ceramic (LavaCeram, 3M ESPE) with 0.5 mm, 1.0 mm, 1.5 mm thicknesses

CONCLUSION

This study showed that proper color matching is a complex process that is influenced by the veneering thickness. Increasing the thickness of the veneer will decrease the color mismatch. Therefore, it can be concluded that the layering technique is preferred with 1.0 mm veneer thickness.

Competing interests

Authors have declared that no competing interests exist.

Authors' Contributions

This work was carried out in collaboration between authors.

REFERENCES

1. Raptis N, Michalakis K, Hirayama H. Optical behavior of current ceramic systems. Int J Periodontics Restor Dent 2006; 26:31–41.
2. Al-Juailaa E, Osman E, Segaana L, Shrebatya M, A. Farghaly E. Comparison of translucency for different thicknesses of recent types of esthetic zirconia ceramics versus conventional ceramics (in vitro study). Future Dental Journal. 2020; 4(2):297-301.
3. Canullo L, Micarelli C, Bettazzoni L, Magnelli A, Baldissara P. Shear bond strength of veneering porcelain to zirconia after argon plasma treatment. Int J Prosthodont 2014; 27:137-9.
4. Tezulas E, Yildiz C, Kucuk C, Kahramanoglu E. Current status of zirconia-based all-ceramic restorations fabricated by the digital veneering technique: a comprehensive review. Int J Comput Dent. 2019;22(3):217-230.
5. Kanat-Ertürk B, Çömlekoğlu EM, Dündar-Çömlekoğlu M, Özcan M, Güngör MA. Effect of Veneering Methods on Zirconia Framework-Veneer Ceramic Adhesion and Fracture Resistance of Single Crowns. J Prosthodont. 2015; 24(8):620-628.
6. Kanat B, Cömlekoğlu EM, Dündar-Çömlekoğlu M, Hakan Sen B, Ozcan M, Ali Güngör M. Effect of various veneering techniques on mechanical strength of computer-controlled zirconia framework designs. J Prosthodont. 2014 ;23(6):445-455.
7. Kim HK, Kim SH. Effect of the number of coloring liquid applications on the optical properties of monolithic zirconia. Dental Materials 2014; 30:229-237.
8. de Azevedo Cubas GB, Camacho GB, Demarco FF, Pereira-Cenci T. The effect of luting agents and ceramic thickness on the color variation of different ceramics against a chromatic background. Eur J Dent 2011; 5:245–252.
9. Tuncel İ, Turp I, Üşümez A. Evaluation of translucency of monolithic zirconia and framework zirconia materials. J Adv Prosthodont 2016 ;8(3):181-186.
10. Pires LA, Novais PMR, Araújo VD, Pegoraro LF. Effects of the type and thickness of ceramic, substrate and cement on the optical color of a lithium disilicate ceramic. J Prosthet Dent 2017; 117: 144-149.
11. Vichi A, Ferrari M, Davidson CL. Influence of ceramic and cement thickness on the masking of various types of opaque posts. J Prosthet Dent 2000; 83:412–417.
12. Shokry TE, Shen CS, Elhosary MM, Elkhodary AM. Effect of core and veneer thicknesses on the color parameters of two all-ceramic systems. J Prosthet Dent 2006; 95:124–129.
13. Ozturk O, Uludag B, Usumez A, Sahin V, Celik G. The effect of ceramic thickness and number of firings on the color of two all-ceramic systems. J Prosthet Dent 2008; 100:99–106.
14. Wahba MM, El- Etreby SA, Morsi ST. Effect of core/veneer thickness ratio and veneer translucency on absolute and relative translucency of CAD-On restorations. Future Dent J 2017; 3 :8-14.
15. O'Keefe KL, Pease PL, Herrin HK. Variables affecting the spectral transmittance of light through porcelain veneer samples. J Prosthet Dent.1991; 66(4):434-438.

16. Chu SJ, Trushkowsky RD, Paravina RD. Dental color matching instruments and systems. Review of clinical and research aspects. J Dent 2010; 38:2-16
17. Bayindir F, Ozbayram O. Effect of number of firings on the color and translucency of ceramic core materials with veneer ceramic of different thicknesses. J Prosthet Dent 2018; 119:152-158.
18. Ghinea R, Pérez MM, Herrera LJ, Rivas MJ, Yebra A, Paravina RD. Color difference thresholds in dental ceramics. J Dent. 2010;38:57-64.
19. Vichi A, Louca C, Corciolani G, Ferrari M. Color related to ceramic and zirconia restorations: a review. Dent Mater 2011; 27: 97–108.
20. Zarone F, Russo S and Sorrentino R.: From porcelain-fused-to-metal to zirconia: clinical and experimental considerations. Dent Mater 2011; 27(1):83-96.
21. Ozkurt Z, Kazazoglu E, Unal A. In vitro evaluation of shear bond strength of veneering ceramics to zirconia. Dent Mater J 2010; 29(2):138-146
22. Stawarczyk B, Emslander A, Roos M, Sener B, Noack F, Keul C. Zirconia ceramics, their contrast ratio and grain size de- pending on sintering parameters. Dent Mater J 2014; 33:591-8.
23. Stawarczyk B, Ozcan M, Hallmann L, Ender A, Mehl A, Hämmerlet CH. The effect of zirconia sintering temperature on flexural strength, grain size, and contrast ratio. Clin Oral Investig 2013; 17:269-74.
24. Jiang L, Liao Y, Wan Q, Li W. Effects of sintering tempera- ture and particle size on the translucency of zirconium diox- ide dental ceramic. J Mater Sci Mater Med 2011; 22:2429-35.
25. Tuncel I, Eroglu E, Sari T, Usumez A. The effect of coloring liquids on the translucency of zirconia framework. J Adv Prosthodont 2013; 5:448-5.
26. Aboushelib MN, De Kler M, Van Der Zel JM, Feilzer AJ. Micro-tensile bond strength and impact energy of fracture of CAD-veneered zirconia restorations. J Prosthodont 2009; 18:211–6.
27. Badr M, Wahsh, M, Salah, T. Effect of veneering techniques and subsequent aging on translucency of bilayered zirconia. Future Dental Journal 2018; 4:274–278
28. Sulaiman TA, Abdulmajeed AA, Donovan TE. Optical properties and light irradiance of monolithic zirconia at variable thicknesses. Dent Mater 2015; 31:1180-1187.
29. Kim M-J, Ahn J-S, Kim J-H, Kim H-Y, Kim W-C. Effects of the sintering conditions of dental zirconia ceramics on the grain size and translucency. J Adv Prosthe 2013; 5:161-166.
30. Fathi A, Farzin M, Giti R, Kalantari MH. Effects of number of firings and veneer thickness on the color and translucency of 2 different zirconia-based ceramic systems. J Prosthet Dent. 2019;122(6):565.e1-565.e7.
31. Jalali H, Alizadeh ES, Sadighpour L, Shabestari GO, Fard MJ. The effect of background and ceramic thickness on the color of an all-ceramic restorative system. J Calif Dent Assoc 2010; 38(3):179-186.
32. Swain MV. Unstable cracking (chipping) of veneering porcelain on all ceramic dental crowns and fixed partial dentures. Acta Biomater 2009; 5:1668-1677.
33. Lund PS, Aquilino SA, Dixon DL. Evaluation of the color and appearance of a new textured opaque porcelain. Int J Prosthodont. 1991; 4:548–554.
34. Regoni P, Amaral FLB, Franca FMG, Basting RT. Color agreement between nanofluoroapatite ceramic discs associated with try-in pastes and with resin cements. Braz Oral Rest 2012; 26:516-522.
35. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucency of six all ceramic systems. Part II: core and veneer materials. J Prosthet Dent 2002; 88:10-15.
36. Chang J, Da Silva JD, Sakai M, Kristiansen J, Ishikawa-Nagai S. The optical effect of composite luting cement on all ceramic crowns. J Dent 2009; 37:937–943.
37. Tabatabaian F, Habib Khodaei M, Namdari M, Mahshid M. Effect of cement type on the color attributes of a zirconia ceramic. J Adv Prosthodont. 2016; 8(6):449-456.
38. Sarac D, Sarac YS, Yuzbasioglu E, Bal S. The effects of porcelain polishing systems on color and surface texture of feldspathic porcelain. J Prosth Dent 2006; 96:122-128.
39. Mahrouse AE. Effect of veneering thickness and technique on color and strength of shaded zirconia core veneered ceramic. Egyptian dental Journal 2014; 60, 937:951.

40. Kielbassa AM, Beheim-Schwarzbach NJ, Neumann K and Zantner C. In vitro comparison of visual and computeraided pre-and post-tooth shade determination using various home bleaching procedures. J Prosthet Dent 2009; 101(2):92-100.
41. Tabatabaian F. Color in zirconia-based restorations and related factors: A literature review. J Prosthodont. 2018; 27:201–11.
42. Seghi RR, Johnston WM and O'Brien WJ. Performance assessment of colorimetric devices on dental porcelains. J Dent Res 1989; 68(12):1755-9.
43. Ragain JC, Johnston WM. Minimum color differences for discriminating mismatch between composite and tooth color. J Esthet Restor Dent 2001; 13(1):41-48.
44. Khashayar G, Bain P, Salari S, Dozie A, Kleverlaan CJ, Feilzer AJ. Perceptibility and acceptability thresholds for color differences in dentistry. J Dent 2014; 42:637-644.
45. Turgut S, Bagis B. Effect of resin cement and ceramic thickness on final color of laminate veneers: an in vitro study. J Prosthet Dent 2013; 109(3):179-186.
46. Mahrouse A, Anwar, E, Sallam H. Effect of veneering thickness and technique on color and strength of shaded zirconia core veneered ceramic. Egyptian dental journal 2014;60:937-951.
47. Dozic A, Kleverlaan CJ, Meegdes M, van der Zel J, Feilzer AJ. The influence of porcelain layer thickness on the final shade of ceramic restorations. J Prosthet Dent 2003; 90:563–570.
48. Uludag B, Usumez A, Sahin V, Eser K and Ercoban E. The effect of ceramic thickness and number of frings on the color of ceramic systems: an in vitro study. J Prosthet Dent 2007; 97(1):25-31.
49. Son HJ, Kim WC, Jun SH, Kim YS, Ju SW and Ahn JS. Infuence of dentin porcelain thickness on layered all-ceramic restoration color. J Dent 2010;38 (2): 71-77.
50. Barizon KT, Bergeron C, Vargas MA, Qian F, Cobb DS, Gratton DG, Geraldeli S. Ceramic materials for porcelain veneers: part II Effect of material, shade, and thickness on translucency. J Prosthet Dent. 2014; 112:864–70.
51. Choi YJ, Razzoog ME. Masking ability of zirconia with and without veneering porcelain. J Prosthodont. 2013 ;22:98–104.
52. Tabatabaian F, Aflatoonian K, Namdari M. Effects of veneering porcelain thickness and background shade on the shade match of zirconia-based restorations. J Dent Res Dent Clin Dent Prospects. 2019; 13(1):68-74.
53. Bachhav VC, Aras MA. The effect of ceramic thickness and number of firings on the color of a zirconium oxide based all ceramic system fabricated using CAD/CAM technology. J Adv Prosthodont. 2011 ;3(2):57-62.