THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

The effect of restoration thickness and resin cement shade on the color and translucency of a high-translucency monolithic zirconia

Funda Bayindir, DDS, PhD[a] and Merve Koseoglu, DDS[b]

ABSTRACT

Statement of problem. Information regarding the influence of cements and material thickness on the final color of monolithic zirconia restorations is lacking.

Purpose. The purpose of this in vitro study was to examine the effect of varying resin cement colors and material thicknesses on the color and translucency of a high-translucency monolithic zirconia and to compare these effects with those reported in similar studies that examined other dental zirconia materials.

Material and methods. Katana High Translucent (Kuraray) was used as a monolithic zirconia material. A total of 80 disk specimens (10 mm in diameter) were made in 4 different thicknesses of 0.5 mm, 1 mm, 1.5 mm, and 2 mm (n=20 per thickness). The color of the specimens (Commission Internationale de l'Eclairage [CIE] L*, a*, b* values) before cementation was measured using a spectrophotometer. Specimens within each thickness were further divided into 2 groups: transparent (n=10) and opaque (n=10). A transparent or opaque self-etch adhesive resin cement (Panavia V5) was then applied to each specimen. After cementation, the color was measured again. The translucency parameter (TP) and ΔE were calculated and evaluated with the color measurements by using descriptive statistics, correlation analysis, single specimen *t* test, 2-way ANOVA, and the Tukey Honestly Significant Difference (HSD) test.

Results. Statistically significant (*P*<.001) changes were found with the increasing thicknesses of the high-translucency zirconia specimens. The TP, L*, and b* values decreased, whereas the a* values increased. In both the transparent and opaque groups, statistically significant (*P*<.001) increases in L*, a*, and b* values and a significant decrease in TP were found with cementation. The lowest ΔE value (1.19 for 2 mm) was observed for monolithic zirconia-clear cement. The highest ΔE value (8.05 for the 0.5 mm) was observed for the monolithic zirconia and opaque cement combination.

Conclusions. Material thickness and cement color affected the color and translucency of high-translucent monolithic zirconia, with effects similar to those observed with other monolithic zirconia materials. (J Prosthet Dent 2020;123:149-54)

For patient satisfaction, restoration of missing teeth and tooth tissues with biocompatible materials that are resistant to occlusal forces also require attention to esthetics.[1,2] Esthetic restorations should be able to mimic the natural color depth of teeth, luminous transmittance, and anatomic structures.[2]

In recent years, monolithic zirconia crowns have been developed.[3] Monolithic zirconias, which are produced with computer-aided design and computer-aided manufacturing (CAD-CAM) systems, consist of atoms interpenetrating without any organic binder and also have high dimensional stability.[3,4] Because they have a natural appearance, they do not need to be veneered with feldspathic ceramics, and natural tooth color can be obtained by characterization.[5] Therefore, chipping of the veneer porcelain is not a factor.[3,6,7] Monolithic zirconias have high biocompatibility and a nonporous structure,[8] and their abrasion resistance is close to that of natural teeth.[9] They cause significantly lower abrasion in antagonist teeth than veneered zirconia crowns.[10,11] In addition, they can be used in situations with insufficient interocclusal clearance, even at an occlusal thickness of 0.5 mm because of their high resistance to fracture.[12]

This study was supported by the Atatürk University Scientific Research Project (grant: 2016/94).
[a]Professor, Department of Prosthetic Dentistry, Faculty of Dentistry, University of Atatürk, Erzurum, Turkey.
[b]Assistant Professor, Department of Prosthodontics, Faculty of Dentistry, University of Sakarya, Sakarya, Turkey.

Clinical Implications

Successful prosthetic restoration requires attention to optimal esthetic outcomes. Given the findings of this study and its limitations, consideration of cement color (opaque versus translucent) and restoration thickness will affect the final color and transparency of restorations made with high-translucency monolithic zirconia.

Resin cements are favorable luting agents for indirect esthetic restorations because of their high retentive strength,[13,14] low solubility,[15-17] and resistance to wear.[18,19] The content of resin cement plays an important role in the connection of cement to zirconia. Resin cement systems containing 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) have increased long-term bond strength to zirconia.[20] Hydroxyl groups on the zirconia surface react with the phosphate groups in 10-MDP, and the Z-O-P chemical bond is formed between zirconia and 10-MDP.[21] Primers containing MDP are bonded to the zirconia surface with the covalent bond, copolymerized with methacrylate groups in the content of resin cements, and provide long-term hydrolytic stability.[22,23]

Dual-polymerizing systems have been widely adopted to ensure optimal polymerization of resin cement in deep areas.[24] Most dual-polymerizing resin cements contain benzoyl peroxide/tertiary amines as initiators of autopolymerization.[25] However, they have disadvantages. The slow polymerization in the autopolymerization mode causes the resin to diffuse into the cement, and water droplets enter the primer-cement interface.[26] Therefore, this type of resin cement exhibits low adhesion to tooth structure when it is only autopolymerized.[24] Furthermore, discoloration occurs as a result of the oxidation of the amine used for autopolymerization.[27] The oxidation of the aromatic amines required to initiate the polymerization of composite resins is considered responsible for the color change in dual-polymerizing resin cements.[28]

The performance of dual-polymerizing resin cement has been reported to be impaired under insufficient light.[29,30] In an attempt to overcome these problems, a new autopolymerizing system containing a redox initiator without an amine catalyst has been developed. This system includes chemically stabilized 10-MDP in the primer and exhibits high binding values and long-term color stability.[24] As a result of the interaction between the coinitiators in the primer and the initiators in the resin cement, the conversion of monomers is initiated without the need for light. This mechanism accelerates the polymerization process of the cement contacting the primer.[31] This system ensures that adhesive failures between the tooth and cement do not occur in the autopolymerization mode.[24] Therefore, in the present study, resin cement containing 10-MDP was selected for its high binding values to zirconia,[22-24] its long-term color stability,[28,32] and the advantages of the special polymerization mechanism.[31]

Color and translucency can be measured by using spectrophotometers.[33-37] These instruments provide numerical expressions of color in a 3D space. According to Commission Internationale de l'Eclairage (CIE) Lab color coordinates, L* represents the lightness of the object, and a* and b* represent the location of the object on the blue/green to red/purple axis and the purple/blue to yellow axis, respectively.[37-43]

The color difference (ΔE) can be determined by comparing the differences between respective coordinate values for each object. Visual assessments can represent detectable color differences (perceptibility) or unacceptable color differences (acceptability) that have clinical significance.[44-46] O'Brien et al[47] interpreted color differences clinically by classifying acceptable values.

Factors such as form, size, surface structure, color, and translucency are important for esthetic restorations.[48-50] The final color of a translucent material can be affected by the cement shade, underlying tooth color, and thickness of the restorative material.[51-54] The authors are unaware of previous studies on the effect of thickness reduction on the color and translucency of high-translucency monolithic zirconia materials.[54-56] However, in a previous study that evaluated the influence of type of cement on the color and translucency of monolithic zirconia, the color coordinates of each type of cement were not determined appropriately.[57] Information regarding the influence of different cement shades and material thickness on the final color of high-translucency monolithic zirconia restorations is lacking.

The purpose of this in vitro study was to examine the effect of varying resin cement colors and material thicknesses on the color and translucency of a high-translucency monolithic zirconia. A secondary purpose was to compare these effects with those reported in similar studies that examined other dental zirconia materials. The null hypothesis was that resin cement shade and material thickness would not affect the color and translucency of high-translucency monolithic zirconia.

MATERIAL AND METHODS

Eighty zirconia specimens were produced with the CAD-CAM system from high-translucency monolithic zirconia (Katana High Translucent; Kuraray Noritake) blocks. The specimens were prepared 25% larger to account for sintering shrinkage and sintered in a furnace

(Protherm Furnaces; Alser Technic Seramic) for 2 hours at 1550 °C.

After the sintering procedure, the specimens were allowed to cool to room temperature. The surface of the specimens was finished with abrasive paper #180 with water-cooling. The specimens were divided into 4 groups according to their thickness: 0.5 mm, 1 mm, 1.5 mm, and 2 mm.

Transparent and opaque self-etch adhesive resin cement (Panavia V5; Kuraray Noritake) was used to cement a 0.1-mm thickness as used in previous studies.[53,58] The cement thickness was standardized with metal plates that were prepared to be 0.1 mm thicker than the thickness of the specimens. Each metal plate (thicknesses of 0.6 mm, 1.1 mm, 1.6 mm, and 2.1 mm) had ten 10-mm diameter holes.

The specimens were placed in the holes in the plates. The adhesive resin cement was placed on the unglazed surfaces of the specimens with the help of special tips in accordance with manufacturer's instructions. A transparent tape (Transparent Strips, Tor VM) was placed on the specimens to provide separation. The cemented glass was placed on the transparent tape to provide a uniform cement thickness. The specimens cemented with transparent color were irradiated for 2 to 3 seconds with a light-polymerization device (Woodpecker Light Cure LED-D; Guilin Woodpecker Medical Instrument), and residual cement was cleaned. The cement was then irradiated for 10 seconds in accordance with the manufacturer's instructions. Because the opaque cement was polymerized only chemically (autopolymerizing), it was not irradiated and was allowed to polymerize in the mold for 3 minutes in accordance with the manufacturer's instructions. After polymerization of the adhesive resin cement had been completed, the disk-shaped specimens were removed from the molds.

The reflectance spectrophotometer device (SpectroShade; MHT Optic Research AG) was calibrated in accordance with the manufacturer's instructions before each measurement.[59,60] The CIELab values were measured using a spectrophotometer on each of the 80 specimens prepared. For each specimen, measurements were made at 3 different points on the black (b), white (w), and gray backgrounds, and the mean value of these measurements was obtained. The translucency parameter (TP) was calculated by placing the Lw, aw, bw and Lb, ab, bb values (as obtained by the spectrophotometer) of the specimens placed on the white (w) and black (b) background into the following formula: $TP=([Lb-Lw]^2+[ab-aw]^2+[bb-bw]^2)^{1/2}$.

The ΔE formula was used to evaluate the effect of different thicknesses of the same specimen and different colors of the cement applied on color: $\Delta E=([\Delta L^*]^2+[\Delta a^*]^2+[\Delta b^*]^2)^{1/2}$. The data were evaluated using a statistical software program (IBM SPSS Statistics, v20.0; IBM Corp). The TP and color difference (ΔE) were calculated and evaluated with the color measurements by using descriptive statistics, correlation analysis, single specimen *t* test, 2-way ANOVA, and the Tukey Honestly Significant Difference (HSD) test.

Table 1. Translucency parameter, L*, a*, and b* values before cementation of specimens (mean ±standard deviation)

Thickness	N	Translucency Parameter	L*	a*	b*
0.5 mm	20	18.7 ±0.5	76.1 ±0.5	-1.0 ±0.03	22.0 ±0.1
1 mm	20	15.0 ±0.5	75.2 ±0.2	-0.6 ±0.05	21.1 ±0.1
1.5 mm	20	10.9 ±0.2	74.0 ±0.2	0.1 ±0.02	20.5 ±0.2
2 mm	20	8.8 ±0.2	73.2 ±0.1	0.6 ±0.02	20.3 ±0.3

Table 2. Translucency parameter, L*, a*, and b* values obtained after cementation of specimens (mean ±standard deviation)

Cement Shades	Translucency Parameter	L*	a*	b*
Clear shade				
0.5 mm	16.11 ±0.20[a]	79.07 ±0.23[a]	-0.30 ±0.02[a]	24.04 ±0.10[a]
1 mm	13.58 ±0.25[b]	77.26 ±0.34[b]	0.11 ±0.02[b]	22.51 ±0.09[b]
1.5 mm	10.47 ±0.34[c]	75.55 ±0.25[c]	0.64 ±0.02[c]	21.54 ±0.11[c]
2 mm	8.74 ±0.17[c]	74.05 ±0.21[d]	0.92 ±0.04[d]	21.05 ±0.15[d]
Opaque shade				
0.5 mm	10.50 ±0.32[a]	83.57 ±0.24[a]	0.47 ±0.05[a]	24.52 ±0.06[a]
1 mm	8.56 ±0.28[b]	80.74 ±0.38[b]	0.71 ±0.05[b]	23.06 ±0.13[b]
1.5 mm	6.67 ±0.26[c]	78.61 ±0.32[c]	1.24 ±0.04[c]	22.06 ±0.19[c]
2 mm	5.83 ±0.21[c]	76.80 ±0.26[d]	1.52 ±0.02[d]	21.52 ±0.10[d]

Similar superscript letters indicate no statistically significant difference (P>.05).

RESULTS

Specimens 0.5 mm in thickness had the highest TP, L*, and b* values and the lowest a* values. Specimens 2 mm in thickness had the lowest TP, L*, and b* values and the highest a* values (P<.001) (Table 1). The Pearson correlation test results revealed a negative correlation between material thickness and TP, L*, a*, and b* values and also a positive correlation between material thickness and b* values. As the material thickness increased, the TP, L*, and b* values decreased, whereas the a* values increased (P<.001). The TP, L*, a*, and b* values and standard deviations of the specimens after cementation are presented in Table 2.

According to the Pearson correlation test results, as the thickness increased in the specimens cemented with both transparent and opaque cement, the TP, L*, and b* values decreased and the a* values increased (P<.001). According to the Student *t* test results, in all thickness groups, the mean L*, a*, and b* values of the specimens cemented with opaque cement were higher than those cemented with transparent cement (P<.001). Furthermore, the mean TP values of the specimens cemented with transparent cement at all thicknesses were higher than those of the specimens cemented with opaque cement (P<.001).

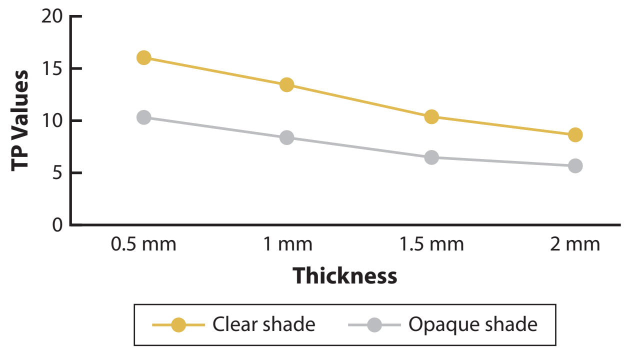

Figure 1. Mean values of TP for cement shade and monolithic zirconia thickness. TP, translucency parameter.

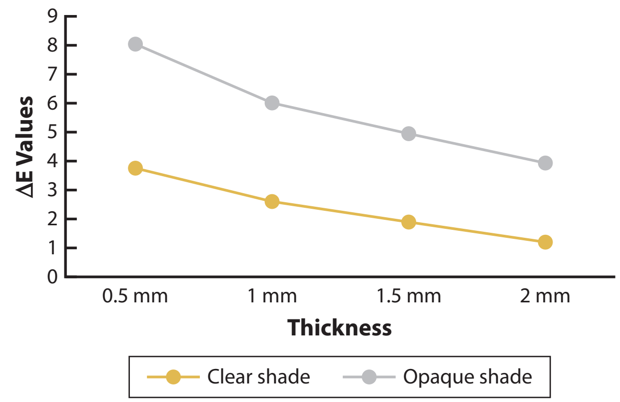

Figure 2. Mean ΔE values for cement shade and monolithic zirconia thickness.

Table 3. ΔL, Δa, Δb, and ΔE values for thickness and cement shades (mean ±standard deviation)

	ΔL	Δa	Δb	ΔE
Clear shade				
0.5 mm	-3.02 ±0.03^{a}	-1.01 ±0.01^{a}	-2.08 ±0.05^{a}	3.74 ±0.05^{a}
1 mm	-2.01 ±0.03^{b}	-0.71 ±0.01^{b}	-1.53 ±0.04^{b}	2.59 ±0.05^{b}
1.5 mm	-1.51 ±0.01^{c}	-0.52 ±0.01^{c}	-1.05 ±0.02^{c}	1.87 ±0.03^{c}
2 mm	-0.84 ±0.02^{d}	-0.32 ±0.02^{d}	-0.83 ±0.01^{d}	1.19 ±0.04^{d}
Opaque shade				
0.5 mm	-7.51 ±0.01^{a}	-1.53 ±0.02^{a}	-2.54 ±0.03^{a}	8.05 ±0.03^{a}
1 mm	-5.49 ±0.02^{b}	-1.32 ±0.06^{b}	-2.07 ±0.03^{b}	5.98 ±0.02^{b}
1.5 mm	-4.56 ±0.03^{c}	-1.13 ±0.02^{c}	-1.53 ±0.03^{c}	4.92 ±0.03^{c}
2 mm	-3.59 ±0.02^{d}	-0.91 ±0.01^{d}	-1.35 ±0.02^{d}	3.91 ±0.02^{d}

Similar superscript letters indicate no statistically significant difference (*P*>.05).

The 2-way ANOVA results indicated that the TP values of the specimens obtained after cementation were significantly influenced by the thickness of the specimens (df=3; F=2238.86; *P*<.001) and cement shades (df=1; F=5885.78; *P*<.001) (Fig. 1). Although changes in the L* values (ΔL), a* values (Δa), b* values (Δb), and color change (ΔE) values before and after cement application were observed to be highest in the specimens cemented with 0.5-mm-thick opaque cement, the lowest values were observed in the specimens cemented with 2-mm-thick transparent cement (Table 3).

The 2-way ANOVA results indicated that the ΔE values of the specimens were significantly influenced by the thickness of the specimens (df=3; F=25 731.65; *P*<.001) and cement shades (df=1; F=143 299.08; *P*<.001) (Fig. 2). The Pearson correlation test results revealed a negative correlation between thickness and ΔL, Δa, Δb, and ΔE. As the thickness increased in the transparent and opaque cement group, the amount of ΔL, Δa, Δb, and ΔE decreased (*P*<.001). According to the Student *t* test results, the ΔL, Δa, Δb, and ΔE values in opaque cement at all thicknesses were larger than those in transparent cement (*P*<.001). A clinically incompatible color change was observed in the 0.5-mm-thick specimens with transparent and opaque cement (ΔE>3.7). In 1-mm-thick specimens, a clinically incompatible color change (ΔE>3.7) was observed in opaque cement, and in transparent cement, a clinically accepted (which was perceived by 100% of observers) color change (ΔE=2-3.7) was seen in the specimens. In specimens 1.5 mm in thickness, a clinically incompatible color change (ΔE>3.7) was observed in opaque cement, and a clinically perceived (which was partially perceptible by 50%) color change (ΔE=1-2) was observed in transparent cement. In specimens 2 mm in thickness, a clinically incompatible color change (ΔE>3.7) was observed in opaque cement, and a clinically perceived (which was partially perceptible by 50%) color change (ΔE=1-2) was observed in transparent cement.

DISCUSSION

The null hypothesis that the shade of resin cement and material thickness would influence the final color and translucency of high-translucency monolithic zirconia was accepted. Zirconia ceramic is a suitable framework material because of its whitish-opaque appearance but appears unnatural in esthetic dental restorations. Recently, colored zirconia with increased translucency has improved the appearance of zirconia,[6] enabling a monolithic design.[3] In the present study, a high-translucency monolithic zirconia material (Katana High Translucent) was tested because of its sustainability to high fracture loads,[6] resistance to low-temperature degradation,[6] and good optical properties.[7,8]

Color measurement devices can provide reproducibility and express results in terms of color colordinates.[49] Spectrophotometers have been reported to be the most useful, applicable, and accurate devices for dental color measurement.[59,60] Therefore, a spectrophotometer was used for color measurement in the present study.

Traditionally, the CIELab color coordinates have been used to assess color in dentistry.[37] These coordinates are used to calculate color differences between 2 objects or specimens to identify their perceptibility and clinical acceptability.[39] In the present study, the calculation of color differences using the CIELab formulas allowed for comparisons with previous studies.[50-52,54-57]

Different values of color change for perceptible and acceptable thresholds have been reported. The acceptable ΔE threshold in different investigations has ranged from 1.7 to 6.8, and the perceptible ΔE threshold, from 1.0 to 3.7.[33-36,39] In this study, the clinical tolerance threshold values reported by O'Brien[47] were used as in a previous study.[46]

In the CIELab color system, the translucency of materials is typically determined by using the TP or contrast ratio.[36,37] Previous studies have used TPs to evaluate the translucencies of dental restorative materials.[36-39] The present study revealed that TP values increased with decreasing thickness in all groups. These results are consistent with those of Kim et al,[54] Sulaiman et al,[55] Church et al,[56] and Malkondu et al,[57] who reported that monolithic zirconia translucency values were affected by thickness. In the present study, the TP values of zirconia specimens also decreased after cementation, as also reported by Malkondu et al.[57]

Cement shade and restoration thickness have an effect on the color of a translucent material.[50-53] In the present study, similar to the results reported by Kim et al[54] on monolithic zirconia, the a* values increased while the L* and b* values decreased as the material thickness increased.

Similar to the results reported by Malkondu et al,[57] ΔE values decreased when thickness increased. However, the mean ΔE values obtained from this study differed from that of the study by Malkondu et al.[57] A possible explanation is that the types, shades, thicknesses, and brands of materials used in the 2 studies were different.

Limitations of this study included the use of 1 type of monolithic zirconia of a single shade. Another limitation was that 1 type of cement of 2 shades was used in this study. Further studies are needed to evaluate the effects of a wider range of cement shades on the color and translucency of high-translucency monolithic zirconia restorations. The final color of a ceramic material is influenced not only by the thickness of the material and cement shades but also by the underlying tooth color.[52,53]

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The final color and TP values of high-translucency monolithic zirconia specimens were affected by material thickness and cement shade.
2. TP values significantly increased with the decrease in monolithic zirconia thickness from 2.0 mm to 0.5 mm.
3. Variation in the shade of the resin-luting cement and material thicknesses resulted in color changes that are perceptible and near or above clinical acceptability.

REFERENCES

1. Mehulić M, Mehulić K, Kos P, Komar D, Katunarić M. Expression of contact allergy in undergoing prosthodontic therapy patients with oral diseases. Minerva Stomatol 2005;54:303-9.
2. Wall JG, Cipra DL. Alternative crown systems. Is the metal-ceramic crown always the restoration of choice? Dent Clin North Am 1992;36:765-82.
3. Zhang Y, Lee JJW, Srikanth R, Lawn BR. Edge chipping and flexural resistance of monolithic ceramics. Dent Mater J 2013;29:1201-8.
4. Berthelsen CL, Stilley KR. Automated personal health inventory for dentistry: a pilot study. J Am Dent Assoc 2000;131:59-66.
5. Zhang Y. Making yttria-stabilized tetragonal zirconia translucent. Dent Mater J 2014;30:1195-203.
6. Flinn BD, Raigrodski AJ, Mancl LA, Toivola R, Kuykendall T. Influence of aging on flexural strength of translucent zirconia for monolithic restorations. J Prosthet Dent 2017;117:303-9.
7. Sulaiman TA, Abdulmajeed AA, Donovan TE, Ritter AV, Lassila LV, Vallittu PK, et al. Degree of conversion of dual-polymerizing cements light polymerized through monolithic zirconia of different thicknesses and types. J Prosthet Dent 2015;114:103-8.
8. Marchack BW, Sato S, Marchack CB, White SN. Complete and partial contour zirconia designs for crowns and fixed dental prostheses: a clinical report. J Prosthet Dent 2011;106:145-52.
9. Batson ER, Cooper LF, Duqum I, Mendonca G. Clinical outcomes of three different crown systems with CAD-CAM technology. J Prosthet Dent 2014;112:770-7.
10. Özcan M. Evaluation of alternative intra oral repair techniques for fractured ceramic fused to metal restorations. J Oral Rehabil 2003;30:194-203.
11. Sripetchdanond J, Leevailoj C. Wear of human enamel opposing monolithic zirconia, glass ceramic, and composite resin: an in vitro study. J Prosthet Dent 2014;112:1141-50.
12. Nakamura K, Harada A, Inagaki R, Kanno T, Niwano Y, Milleding P, et al. Fracture resistance of monolithic zirconia molar crowns with reduced thickness. Acta Odontol Scand 2015;73:602-8.
13. Abo-Hamar SE, Hiller KA, Jung H, Federlin M, Friedl KH, Schmalz G. Bond strength of a new universal self-adhesive resin luting cement to dentin and enamel. Clin Oral Investig 2005;9:161-7.
14. Nakamura T, Wakabayashi K, Kinuta S, Nishida H, Miyamae M, Yatani H. Mechanical properties of new self-adhesive resin-based cement. J Prosthodont Res 2010;54:59-64.
15. Yoshida K, Tanagawa M, Atsuta M. In-vitro solubility of three types of resin and conventional luting cements. J Oral Rehabil 1998;25:285-91.
16. Eisenburger M, Addy M, Rossbach A. Acidic solubility of luting cements. J Dent 2003;31:137-42.
17. Hill EE, Lott J. A clinically focused discussion of luting materials. Aust Dent J 2011;56:67-76.
18. Braga RR, Condon Jr, Ferracane JL. In vitro wear stimulation measurements of composite versus resin-modified glass ionomer luting cements for all ceramic restorations. J Esthet Restor Dent 2002;14:368-76.
19. Takamizawa T, Barkmeier WW, Latta MA, Berry TP, Tsujimoto A, Miyazaki M. Simulated wear of self-adhesive resin cements. Oper Dent 2016;41:327-38.
20. Rebholz-Zaribaf N, Özcan M. Adhesion to zirconia as a function of primers/silane coupling agents, luting cement types, aging and test methods. J Adhes Sci Technol 2017;31:1408-21.
21. Chen L, Suh BI, Brown D, Chen X. Bonding of primed zirconia ceramics: evidence of chemical bonding and improved bond strengths. Am J Dent 2012;25:103-8.
22. Khan AA, Al Kheraif AA, Syed J, Divakar DD, Matinlinna JP. Effect of experimental primers on hydrolytic stability of resin zirconia bonding. J Adhes Sci Technol 2017;31:1094-104.
23. Yoshida K, Tsuo Y, Atsuta M. Bonding of dual-cured resin cement to zirconia ceramic using phosphate acid ester monomer and zirconate coupler. J Biomed Mater Res B Appl Biomater 2006;7:28-33.
24. Tagami A, Takahashi R, Nikaido T, Tagami J. The effect of curing conditions on the dentin bond strength of two dual-cure resin cements. J Prosthodont Res 2017;61:412-8.
25. Tay FR, King N, Suh B, Pashley DH. Effect of delayed activation of light-cured resin composites on bonding of all-in-one adhesives. J Adhes Dent 2001;3:207-25.

26. Yang B, Ludwig K, Adelung R, Kern M. Micro-tensile bond strength of three luting resins to human regional dentin. Dent Mater J 2006;22:45-56.
27. Jung H, Friedl KH, Hiller KA, Haller A, Schmalz G. Curing efficiency of different polymerization methods through ceramic restorations. Clin Oral Investig 2001;5:156-61.
28. Lu H, Powers J. Color stability of resin cements after accelerated aging. Am J Dent 2004;17:354-8.
29. Tashiro H, Inai N, Nikaido T, Tagami J. Effects of light intensity through resin inlays on the bond strength of dual-cured resin cement. J Adhes Dent 2004;6:233-8.
30. Shimura R, Nikaido T, Yamauti M, Ikeda M, Tagami J. Influence of curing method and storage condition on microhardness of dual-cure resin cements. Dent Mater J 2005;24:70-5.
31. Kawano S, Fu J, Saikaew P, Chowdhury AA, Fukuzawa N, Kadowaki Y, et al. Microtensile bond strength of a newly developed resin cement to dentin. Dent Mater J 2015;34:61-9.
32. Müller JA, Rohr N, Fischer J. Evaluation of ISO 4049: water sorption and water solubility of resin cements. Eur J Oral Sci 2017;125:141-50.
33. Chu SJ, Trushkowsky RD, Paravina RD. Dental color matching instruments and systems. Review of clinical and research aspects. J Dent 2010;38:2-16.
34. Seghi RR, Hewlett ER, Kim J. Visual and instrumental colorimetric assessments of small color differences on translucent dental porcelain. J Dent Res 1989;68:1760-4.
35. Kuehni RG, Marcus RT. An experiment in visual scaling of small color differences. Color Res Appl 1979;4:83-91.
36. Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. J Dent Res 1989;68:819-22.
37. Johnston WM, Ma T, Kienle BH. Translucency parameter of colorants for maxillofacial prostheses. Int J Prosthodont 1995;8:79-86.
38. Antonson SA, Anusavice KJ, Antonson SA, Anusavice KJ. Contrast ratio of veneering and core ceramics as a function of thickness. Int J Prosthodont 2001;14:316-20.
39. Ahn JS, Lee YK. Difference in the translucency of all-ceramics by the illuminant. Dent Mater J 2008;24:1539-44.
40. Ilday NO, Celik N, Bayindir YZ, Seven N. Effect of water storage on the translucency of silorane-based and dimethacrylate-based composite resins with fibres. J Dent 2014;42:746-52.
41. Ruyter IE, Nilner K, Möller B. Color stability of dental composite resin materials for crown and bridge veneers. Dent Mater J 1987;3:246-51.
42. Rosenstiel SF, Johnston WM. The effects of manipulative variables on the color of ceramic metal restorations. J Prosthet Dent 1988;60:297-303.
43. Ghinea R, Pérez MM, Herrera LJ, Rivas MJ, Yebra A, Paravina RD. Color difference thresholds in dental ceramics. J Dent 2010;38:57-64.
44. Douglas RD, Steinhauer TJ, Wee AG. Intraoral determination of the tolerance of dentists for perceptibility and acceptability of shade mismatch. J Prosthet Dent 2007;97:200-8.
45. Wee AC, Kang EY, Jere D, Beck FM. Clinical color match of porcelain visual shade-matching systems. J Esthet Restor Dent 2015;17:351-7.
46. 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;119:152-8.
47. O'Brien WJ, Hemmendinger H, Boenke KM, Linger JB, Groh CL. Color distribution of three regions of extracted human teeth. Dent Mater J 1997;13:179-85.
48. Chen YM, Smales RJ, Yip KHK, Sung WJ. Translucency and biaxial flexural strength of four ceramic core materials. Dent Mater J 2008;24:1506-11.
49. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucency of six all-ceramic systems. Part I: core materials. J Prosthet Dent 2002;88:4-9.
50. 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.
51. Alqahtani MQ, Aljurais RM, Alshaafi MM. The effects of different shades of resin luting cement on the color of ceramic veneers. Dent Mater J 2012;31:354-61.
52. Dede DO, Armaganci A, Ceylan G, Cankaya S, Celık E. Influence of abutment material and luting cements color on the final color of all ceramics. Acta Odontol Scand 2013;71:1570-8.
53. 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;83:412-7.
54. Kim HK, Kim SH, Lee JB, Han JS, Yeo IS, Ha SR. Effect of the amount of thickness reduction on color and translucency of dental monolithic zirconia ceramics. J Adv Prosthodont 2016;8:37-42.
55. Sulaiman TA, Abdulmajeed AA, Donovan TE, Ritter AV, Vallittu PK, Narhi TO, et al. Optical properties and light irradiance of monolithic zirconia at variable thicknesses. Dent Mater J 2015;31:1180-7.
56. Church TD, Jessup JP, Guillory VL, Vandewalle KS. Translucency and strength of high-translucency monolithic zirconia oxide materials. Gen Dent 2017;65:48-52.
57. Malkondu O, Tinastepe N, Kazazoglu E. Influence of type of cement on the color and translucency of monolithic zirconia. J Prosthet Dent 2016;116:902-8.
58. Lee TH, Ahn JS, Shim JS, Han CH, Kim SJ. Influence of cement thickness on resin-zirconia microtensile bond strength. J Adv Prosthodont 2011;3:119-25.
59. Karamouzos A, Papadopoulos MA, Kolokithas G, Athanasiou AE. Precision of in vivo spectrophotometric colour evaluation of natural teeth. J Oral Rehabil 2007;34:613-21.
60. Paul SJ, Peter A, Rodoni L, Pietrobon N. Conventional visual vs spectrophotometric shade taking for porcelain-fused-to-metal crowns: a clinical comparison. Int J Periodontics Restorative Dent 2004;24:222-31.

Corresponding author:
Dr Funda Bayindir
Atatürk University
Faculty of Dentistry
Department of Prosthodontics
Erzurum
TURKEY
Email: fundabayindir@gmail.com

https://doi.org/10.1016/j.prosdent.2018.11.002