

RESEARCH AND EDUCATION

Influence of coping and veneer thickness on the color of zirconia-based restorations on different implant abutment backgrounds



Farhad Tabatabaian, DDS, MS,^a Alireza Jafari, DDS, MS,^b Mahshid Namdari, PhD,^c and Minoo Mahshid, DDS, MS^d

Shade reproduction of a dental ceramic is crucial for obtaining excellent esthetics in restorative dentistry.¹ Dental ceramic materials have been enhanced to reproduce the appearance of natural teeth.² Manufacturers have introduced different types of dental ceramic to replicate the optical characteristics of natural teeth,³ imitating the translucency of tooth structures including dentin and enamel.⁴ Feldspar, glass, and zirconia ceramics with different optical behaviors have been used to fabricate tooth-like restorations.⁵⁻⁷ Excellent durability and longevity^{3,8-10} are also essential to the selection of a ceramic for a restoration.^{11,12}

Among various dental ceramics, zirconia ceramics have the highest fracture strength and, in this regard, zirconia restorations are comparable to metal-ceramic restorations.^{13,14} However, many zirconia ceramics have lower translucency than tooth structure.¹⁵ The absolute translucency of zirconia ceramic, defined as the percentage of light transmittance

through a 1-mm-thick ceramic, has been determined to be between 20% and 49%.¹⁶ Low to medium translucency zirconia is commonly used in zirconia-based restorations; meanwhile, high- to ultra-translucency zirconia is usually used for monolithic restorations.¹⁷ However, the ultra-level of zirconia translucency may

ABSTRACT

Statement of problem. The effects of coping and veneer thickness on the color of zirconia-based restorations are unknown.

Purpose. The purpose of this in vitro study was to evaluate the influence of coping and veneer thickness on the color of zirconia-based restorations on different implant abutment backgrounds and to define minimum coping and veneer thicknesses for the backgrounds investigated to achieve a target color.

Material and methods. Thirty zirconia disk specimens with thicknesses of 0.4, 0.6, and 0.8 mm and 30 veneering ceramic disk specimens with thicknesses of 0.8, 1.0, and 1.2 mm were fabricated. Three backgrounds were prepared: titanium alloy, zirconia ceramic, and base metal alloy. The zirconia specimens were placed on the backgrounds, and the veneering ceramic specimens were located on the zirconia specimens. Spectrophotometric measurements were made to determine CIE Lab values. Color difference (ΔE) values were calculated to measure color differences between the specimens and the A2 VITA classical shade tab. ΔE values were compared with a perceptibility threshold ($\Delta E=2.6$). Repeated measures ANOVA, Bonferroni test, and 1-sample *t* test were used to analyze data ($\alpha=.05$).

Results. Mean ΔE values ranged from 2.0 to 9.8. Coping thickness, veneer thickness, and their combination significantly affected ΔE ($P<.001$).

Conclusions. To achieve the target color with zirconia-based restorations, regardless of the backgrounds tested, the minimum thickness of zirconia coping should be 0.6 mm, and the minimum thickness of veneering ceramic should be 1.2 mm. (J Prosthet Dent 2019;121:327-32)

Supported by Research Deputy of School of Dentistry of Shahid Beheshti University of Medical Sciences, grant 13168. Mehr Dental Lab provided support for CAD-CAM.

^aAssociate Professor, Department of Prosthodontics, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

^bAssistant Professor, Department of Prosthodontics, School of Dentistry, Bushehr University of Medical Sciences, Bushehr, Iran.

^cAssistant Professor of Biostatistics, Department of Community Oral Health, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

^dProfessor, Department of Prosthodontics, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Clinical Implications

Ceramic thickness and abutment material may affect the color of zirconia-based restorations. This study introduced an esthetic guideline related to coping and veneer thicknesses for implant-supported zirconia-based restorations.

still be insufficient to reproduce the optical properties of tooth structure.¹⁵ This may be a reason to veneer a zirconia coping with feldspathic ceramic to obtain tooth-like translucency. The veneering ceramics with translucency levels close to those of dentin and enamel may enable acceptable shade reproduction for zirconia-based restorations.²

A scientific approach to the evaluation of shade reproduction is to measure L*(lightness), a*(red-green value), and b*(yellow-blue value) values for a restoration and a target color in the CIELab system by using a spectrophotometer and to determine their color differences based on a ΔE formula.¹⁸ The measured ΔE value is then compared with a perceptibility or an acceptability threshold to determine the visibility of the color difference.^{19,20} If the ΔE value is less than the threshold, a proper shade reproduction is confirmed.²¹ Zirconia coping brand²² and thickness,²³ veneering ceramic brand²⁴ and thickness,²⁵ and glazing²⁶ can affect the color of zirconia-based restorations. Some color mismatches have been reported for implant-supported zirconia fixed partial dentures despite their acceptable survival rates.²⁷ Consequently, zirconia abutments rather than titanium abutments have been recommended for implant-supported ceramic restorations in the esthetic zone.^{28,29} Although zirconia-based restorations have been widely used on implant or tooth substructures,²⁷ shade reproduction with these restorations is still unpredictable because of different layers of glaze, veneering ceramic, zirconia coping, cement, background, and their optical effects on the resultant color.

Information about shade reproduction in zirconia-based restorations and how to obtain an intended target color accurately is lacking, although the effect of ceramic thickness on the translucency, shade, and color of zirconia restorations has been reported.³⁰⁻³⁵ Therefore, the purpose of this *in vitro* study was to evaluate the influence of coping and veneer thickness on the color of zirconia-based restorations on different implant abutment backgrounds and to define minimum coping and veneer thicknesses for the backgrounds investigated to achieve a target color. The null hypothesis was that the zirconia coping thickness, the veneering ceramic thickness,

and their combination would not affect the resulting color.

MATERIAL AND METHODS

Thirty zirconia coping disk specimens in 3 thickness groups (0.4, 0.6, and 0.8 mm) and 30 veneering ceramic disk specimens in 3 thickness groups (0.8, 1.0, and 1.2 mm) were tested on 3 different backgrounds to evaluate the resulting color related to different coping-veneer (C-V) thickness combinations. There were 10 specimens in each C-V thickness group. The sample size was calculated from the results of previous studies,^{16,23} an 80% power, and a .05 level of significance.

A computer-aided design and computer-aided manufacturing (CAD-CAM) system (CORiTEC 250i; imes-icore GmbH) was used to mill zirconia blanks (VITA YZ T; VITA Zahnfabrik H. Rauter GmbH & Co KG) to fabricate zirconia disks with 10-mm diameters and the 3 specified thicknesses. Zirconia specimens were dipped in an A2 shade liquid (Medium YZ T COLORING LIQUID; VITA Zahnfabrik H. Rauter GmbH & Co KG) for 2 minutes, left to dry for 30 minutes, and sintered at the maximum temperature of 1530°C for 280 minutes in a sintering furnace (iSINT HT; imes-icore GmbH). Zirconia specimens were then adjusted and polished for 15 minutes by a dental technician using a polishing kit (BruxZir; Glidewell Direct) in a 3-step procedure: a fine-grit diamond rotary instrument using light pressure with water and air spray, a green cup using light pressure and no water, and an orange cup using light to medium pressure and no water, as instructed by the manufacturer.

Veneering ceramic disks with 10-mm diameters and 3 specified thicknesses of an A2 shade feldspar dentin veneering ceramic compatible with zirconia frameworks (VITA VM9 BASE DENTINE; VITA Zahnfabrik H. Rauter GmbH & Co KG) were prepared by using the slip casting technique. The veneer specimens were fired for 69 minutes with a heat rate of 55°C/min from 500°C to 910°C, cooled to room temperature, and polished using a ceramic polishing laboratory kit (LUS41; Hager & Meisinger GmbH). The same dental technician followed a 3-step polishing procedure, using green, purple, and yellow polishing disks, as instructed by the manufacturer. Each specimen was of the specified thickness (± 0.02 mm); otherwise, it was excluded from the study. All zirconia and veneer specimens were cleaned in an ethanol solution and dried with compressed air.

An A2 shade tab from a new shade guide (VITA classical A1-D4 shade guide; VITA Zahnfabrik H. Rauter GmbH & Co KG) was used as the target color (control). CIELab values for the central region of the middle third of this tab were measured ($L^*=75.8$, $a^*=1.3$, $b^*=20.5$) using a spectrophotometer (SpectroShade Micro; MHT Optic Research AG) of documented reliability, validity,

and repeatability ($\Delta E < 0.5$).^{36,37} The color of the A2 shade of the tab was confirmed with this device.

Three cylindrical backgrounds with 10-mm diameters and heights were fabricated from implant abutment materials, including titanium alloy (Ti), zirconia ceramic (Zir), and base metal alloy (BM). To fabricate the background Ti, a titanium alloy blank (TITANEX136; Titanic GmbH) was milled to a cylindrical shape by using the same CAD-CAM system. This background was polished by using a titanium polishing kit (Hatho Titanium Polishing Kit; Keystone Industries). To make the background Zr, a cylindrical pattern was designed with software (SOLIDWORKS 2015; Dassault Systèmes). The same CAD-CAM system was used to mill a similar zirconia blank to fabricate a zirconia cylinder according to the design. The zirconia cylinder was colored by dipping it in an A3 shade liquid for 6 seconds, sintered at 1530°C for 5 hours in the same sintering furnace, and polished with the same zirconia polishing kit. For the background BM, a cylindrical pattern was made using an acrylic resin (Duralay; Reliance Dental Mfg Co). The pattern was cast in a nickel-chromium alloy (VeraBond V; Aalba Dent, Inc) and then polished using a base metal polishing kit (Coral Stones; Shofu Inc). CIELab values of the backgrounds were measured with the same device (values for Ti: $L^* = 6.0$, $a^* = -1.5$, $b^* = -0.2$; values for Zir: $L^* = 72.0$, $a^* = 4.4$, $b^* = 14.2$; and values for BM: $L^* = 9.3$, $a^* = -0.4$, $b^* = 1.1$).

A silicone putty (Speedex; Coltène) was molded to the device to eliminate external light and to duplicate the measurement conditions for all specimens.¹⁶ To include different C-V thickness combinations, each zirconia specimen was matched with 3 veneer specimens (1 per veneer thickness group). Zirconia specimens were placed on the backgrounds, and veneer specimens were located on the zirconia specimens without an intermediate.²² CIELab values (L^* , a^* , and b^*) were measured for zirconia specimens with and without veneer specimens by using the same device. Each measurement was repeated 3 times at the center of the specimens by a trained operator (A.J.), and average values were recorded. ΔE values were calculated to compare the CIELab values of a specimen on the backgrounds with the CIELab values of the target color. ΔE was calculated from the formula: $\Delta E_{ab}^* = ([\Delta L^*]^2 + [\Delta a^*]^2 + [\Delta b^*]^2)^{1/2}$. A threshold for perceptibility ($\Delta E = 2.6$) was assumed to interpret the color differences.¹⁹

Statistical software (IBM SPSS Statistics, v21; IBM Corp) was used for data analysis. The Kolmogorov-Smirnov test indicated a normal distribution of the data in all groups ($P > .05$). Repeated measures ANOVA was used to compare ΔE values among the groups, and ΔE values were evaluated considering coping thickness, veneer thickness, and background type. Pairwise comparisons of the groups were performed using

the Bonferroni adjustment. Using statistical software (STATA; StataCorp LLC) and the 1-sample *t* test, the ΔE values were compared with the perceptibility threshold of $\Delta E = 2.6$ ($\alpha = .05$ for all tests).

RESULTS

The mean CIELab and ΔE values for the combinations of the coping thickness (C0.4, C0.6, C0.8) and the veneer thickness (V0, V0.8, V1.0, V1.2) for the backgrounds (Ti, Zir, BM) are presented in Figure 1 and Supplemental Tables 1 to 4. Repeated measures ANOVA results (Table 1) indicated (Table 1) that the coping thickness ($P < .001$), veneer thickness ($P < .001$), background ($P < .001$), interactions of the coping thickness and veneer thickness ($P < .001$), coping thickness and background ($P = .016$), and veneer thickness and background ($P < .001$) affected the ΔE values; however, the interaction of all of them did not affect the ΔE ($P = .054$). Pairwise comparisons of the ΔE values using the Bonferroni adjustment indicated significant differences between some C-V groups for each background ($P < .05$) and between some backgrounds for each C-V group ($P < .05$).

The 1-sample *t* test was used to compare ΔE values of C-V groups for the studied backgrounds with the perceptibility threshold ($\Delta E = 2.6$). The null hypothesis of $\Delta E \leq 2.6$ was not rejected for C0.6-V1.2 and C0.8-V1.2 for all backgrounds ($P > .05$) and was rejected for the other C-V groups for all backgrounds ($P < .05$) (Supplemental Table 4). Therefore, to achieve the target color, the minimum coping thickness was 0.6 mm, and the minimum veneer thickness was 1.2 mm.

DISCUSSION

Significant differences were found among ΔE values related to coping thickness, veneer thickness, and their combination. Therefore, the null hypothesis of the study was rejected. The minimum thicknesses were 0.6 mm for the coping and 1.2 mm for the veneer to achieve the target color with zirconia-based restorations on the implant abutment backgrounds. This result can be explained by the optical properties of zirconia ceramic and veneering ceramic. Because zirconia ceramic is semi-translucent,²¹ the zirconia coping thickness should be increased to compensate for the background's color effect on the final color.^{16,23} This was confirmed by the present study which showed that a 0.4-mm-thick zirconia coping was insufficient for masking background color. A minimum of 0.6-mm-thick zirconia coping was required to mask the background. However, a zirconia coping alone was not sufficient for an acceptable shade reproduction, even with an increase in its thickness to 0.8 mm (Fig. 1D). This is due to the inhomogeneous polycrystal microstructure of zirconia ceramic, which differs optically from human dentin and has a lower level of translucency.¹⁵

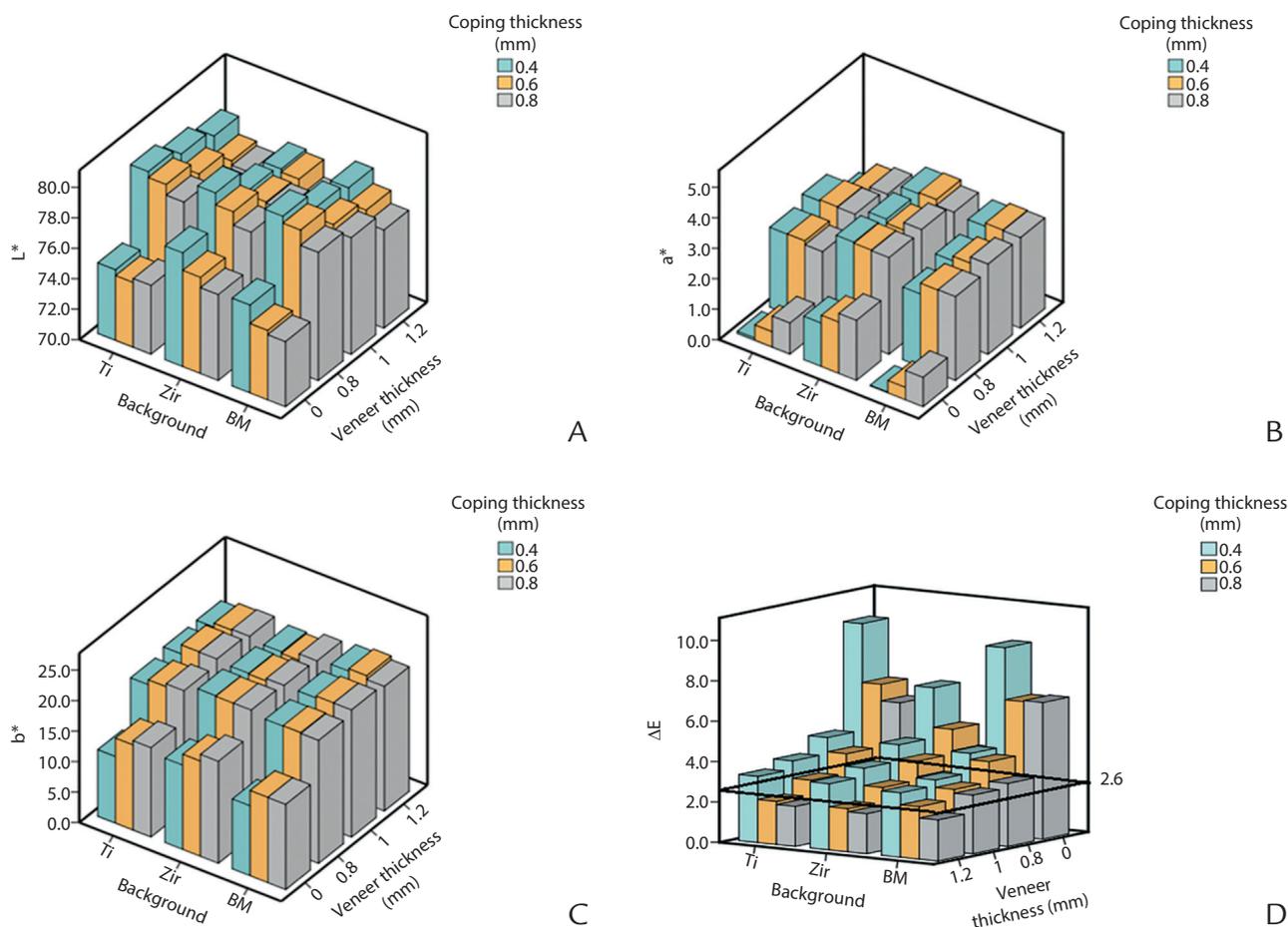


Figure 1. Effects of coping thickness, veneer thickness, and background type on CIE Lab and ΔE values. A, Mean L^* values. B, Mean a^* values. C, Mean b^* values. D, Mean ΔE values. ΔE , color difference; a^* , redness-greenness; b^* , yellowness-blueness; L^* , lightness.

Light is scattered in the zirconia microstructure more than it is absorbed.¹⁵ Internal light scattering at the boundaries induces internal light reflection and refraction.³⁸ With increased light reflection, translucency decreases.³⁸ The light scattering in zirconia is affected by grain sizes and their boundaries, crystalline phase, porosities, additives, defects, and thickness.³⁸ Veneering ceramic with optical properties similar to dentin is more homogenous and translucent than zirconia and, therefore, can replicate the target color and translucency.^{2,24,39} However, the veneering ceramic thickness should be increased to compensate for the background and zirconia.^{4,30,33,39} While veneering ceramic thickness increases, translucency decreases, and the underlying layering effect decreases.^{2,35,39} This may be why the color match achieved in the current study was independent of the background material (zirconia or metal), as the result of an increase in the veneering ceramic thickness from 0.8 to 1.2 mm.

The appropriate perceptibility and acceptability thresholds used in color studies have been debated.^{20,21} The perceptibility threshold determines a limit for the

Table 1. Results of repeated measures ANOVA for effects of coping thickness, veneer thickness, and background type on ΔE

Source	Type III Sum of Squares	df	Mean Square	F	P
Within-Subject Effects					
Background	32.794	1.242	26.398	65.638	<.001
Background×coping thickness	3.861	2.485	1.554	3.864	.016
Background×veneering thickness	73.208	3.727	19.643	48.843	<.001
Background×coping thickness×veneering thickness	6.023	7.454	0.808	2.009	.054
Error (background)	53.958	134.167	0.402		
Between-Subject Effects					
Intercept	5837.239	1	5837.239	8360.500	<.001
Coping thickness	183.109	2	91.554	131.131	<.001
Veneering thickness	998.146	3	332.715	476.538	<.001
Coping thickness×veneering thickness	51.707	6	8.618	12.343	<.001
Error	75.405	108	0.698		

ΔE , color difference.

ΔE color difference detected by expert clinicians, whereas the acceptability threshold regards an untrained observer’s ability to ascertain ΔE color differences.²¹ Therefore, the perceptibility threshold is lower than the

acceptability threshold.²⁰ In this study, the perceptibility threshold was used as a criterion with which to compare the results and, according to Douglas et al,¹⁹ $\Delta E=2.6$ was used. Also, the 3 factors of background, coping, and dentin veneer were evaluated, whereas other factors such as cement, enamel veneer, and glaze were not tested. Because all effective factors in color were not tested in the present study, the perceptibility threshold of $\Delta E=2.6$ rather than the acceptability threshold of $\Delta E=5.5$ ¹⁹ was regarded for evaluation of color differences. This may consider a margin of tolerance for the color differences in order to make a better clinical judgment of the acceptability of final color.

Sinmazisik et al²⁶ reported that zirconia-based restorations with a zirconia coping thickness of less than 0.5 mm and a dentin veneering ceramic thickness of 1 mm resulted in a ΔE value of more than 5.5 (a color mismatch), but an increase in the dentin veneering ceramic thickness from 1 to 1.5 mm resulted in a ΔE value of less than 2.6 (a color match). This was confirmed by the present study, which showed acceptable shade reproduction when the zirconia coping thickness was at least 0.6 mm and the dentin veneering ceramic thickness was at least 1.2 mm. However, the current research evaluated a wider range of thicknesses and defined a more precise C-V thickness cutoff.

Tabatabaian et al²³ reported that a zirconia coping should be increased from 0.4 to 0.8 mm to eliminate the color effect of a base metal background on the color of zirconia-based restorations, regardless of veneering ceramic. A similar result was obtained in the present study; however, the minimum coping thickness determined by the present study was less than that of the study by Tabatabaian et al.²³ This is due to the veneering ceramic used in the current research.

Harada et al²⁵ showed that the translucency and opalescence of zirconia-based restorations were not affected by the 0.5-mm-thick Katana zirconia coping color when the Cerabien ZR veneering ceramic thickness was at least 1.0 ± 0.1 mm. The veneering ceramic thickness was reemphasized in the present study; however, because of the differences in the brand and translucency of the tested ceramics, different C-V thickness cutoffs were introduced by the studies.

Dede et al²⁸ advocated zirconia abutments rather than titanium abutments for lithium disilicate glass-ceramic restorations in terms of esthetics. Their results disagree with those of the present study because of the lower translucency of zirconia than glass-ceramics. This enables zirconia restorations to mask both zirconia and titanium abutments.

Carrillo de Albornoz et al,²⁹ in a randomized trial study, reported a tendency toward better esthetics using zirconia abutments instead of titanium abutments. However, the current study found no color differences

related to abutment material for increased thicknesses of zirconia-based restorations. Results of the studies may be consistent for decreased thicknesses of restorations.

The current study confirmed the results of Barizon et al,² Wang et al,³⁰ Sulaiman et al,³¹ Kim et al,³² Oh and Kim,³³ Shiraishi et al,³⁴ and Jeong et al³⁵ for the significant effect of ceramic thickness on esthetics and also introduced a minimum thickness of 1.8 mm for implant-supported zirconia-based restorations.

Different factors such as background, cement, zirconia coping, veneering ceramic, and glaze impact the color of zirconia-based restorations.³⁹ Also, other factors such as material brand, thickness, surface treatment, and laboratory procedures can affect the color.³⁹ Regarding the factors investigated in the present study, optimum esthetics are achievable with implant-supported zirconia-based restorations regardless of abutment material if minimum thicknesses of 0.6 for the coping and 1.2 mm for the veneer are provided. Therefore, a minimum thickness of 1.8 mm is clinically indicated for these restorations after providing adequate space through abutment selection and preparation. This is recommended as an esthetic guideline for these restorations.

The effects of cement, enamel veneer, and glaze were not evaluated in this study. Also, only 1 brand of zirconia and its compatible veneering ceramic with a specific shade were tested. These limitations are suggestions for consideration in future studies.

CONCLUSIONS

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

1. Coping and veneer thickness and their combination affected the color of zirconia-based restorations on different implant abutment backgrounds.
2. To achieve the target color with zirconia-based restorations regardless of the backgrounds tested, a minimum thickness of zirconia coping should be 0.6 mm and a minimum thickness of veneering ceramic should be 1.2 mm.

REFERENCES

1. Da Silva JD, Park SE, Weber HP, Ishikawa-Nagai S. Clinical performance of a newly developed spectrophotometric system on tooth color reproduction. *J Prosthet Dent* 2008;99:361-8.
2. Barizon KT, Bergeron C, Vargas MA, Qian F, Cobb DS, Gratton DG, et al. Ceramic materials for porcelain veneers: part II. Effect of material, shade, and thickness on translucency. *J Prosthet Dent* 2014;112:864-70.
3. Aldeghisem A, Ioannidis G, Att W, Petridis H. Success and survival of various types of all-ceramic single crowns: a critical review and analysis of studies with a mean follow-up of 5 years or longer. *Int J Prosthodont* 2017;30:168-81.
4. Skyllouriotis AL, Yamamoto HL, Nathanson D. Masking properties of ceramics for veneer restorations. *J Prosthet Dent* 2017;118:517-23.
5. Shono NN, Al Nahedh HN. Contrast ratio and masking ability of three ceramic veneering materials. *Oper Dent* 2012;37:406-16.
6. Carrabba M, Keeling AJ, Aziz A, Vichi A, Fabian Fonzar R, Wood D, et al. Translucent zirconia in the ceramic scenario for monolithic restorations: a flexural strength and translucency comparison test. *J Dent* 2017;60:70-6.

7. Dede DÖ, Ceylan G, Yilmaz B. Effect of brand and shade of resin cements on the final color of lithium disilicate ceramic. *J Prosthet Dent* 2017;117:539-44.
8. Jian Y, He ZH, Dao L, Swain MV, Zhang XP, Zhao K. Three-dimensional characterization and distribution of fabrication defects in bilayered lithium disilicate glass-ceramic molar crowns. *Dent Mater* 2017;33:178-85.
9. Santos MJ, Freitas MC, Azevedo LM, Santos GC Jr, Navarro MF, Francischone CE, et al. Clinical evaluation of ceramic inlays and onlays fabricated with two systems: 12-year follow-up. *Clin Oral Investig* 2016;20:1683-90.
10. Saied MA, Lloyd IK, Haller WK, Lawn BR. Joining dental ceramic layers with glass. *Dent Mater* 2011;27:1011-6.
11. Zaher AM, Hochstedler JL, Rueggeberg FA, Kee EL. Shear bond strength of zirconia-based ceramics veneered with 2 different techniques. *J Prosthet Dent* 2017;118:221-7.
12. Duan Y, Griggs JA. Effect of elasticity on stress distribution in CAD/CAM dental crowns: glass ceramic vs. polymer-matrix composite. *J Dent* 2015;43:742-9.
13. Elsaka SE, Elnaghy AM. Mechanical properties of zirconia reinforced lithium silicate glass-ceramic. *Dent Mater* 2016;32:908-14.
14. Monaco C, Rosentritt M, Llukacej A, Baldissara P, Scotti R. Marginal adaptation, gap width, and fracture strength of teeth restored with different all-ceramic vs metal ceramic crown systems: an in vitro study. *Eur J Prosthodont Restor Dent* 2016;24:130-7.
15. Pecho OE, Ghinea R, Ionescu AM, Cardona JC, Della Bona A, Pérez Mdel M. Optical behavior of dental zirconia and dentin analyzed by Kubelka-Munk theory. *Dent Mater* 2015;31:60-7.
16. Tabatabaian F, Dalirani S, Namdari M. Effect of thickness of zirconia ceramic on its masking ability: an in vitro study. *J Prosthodont* 2017 Apr 28. doi: 10.1111/jopr.12625. [Epub ahead of print].
17. Stawarczyk B, Keul C, Eichberger M, Figge D, Edelhoft D, Lünkemann N. Three generations of zirconia: From veneered to monolithic. Part II. *Quintessence Int* 2017;48:441-50.
18. Yoshida A, Miller L, Da Silva JD, Ishikawa-Nagai S. Spectrophotometric analysis of tooth color reproduction on anterior all-ceramic crowns. Part 2: Color reproduction and its transfer from in vitro to in vivo. *J Esthet Restor Dent* 2010;22:53-63.
19. 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.
20. Khashayar G, Bain PA, Salari S, Dozic A, Kleverlaan CJ, Feilzer AJ. Perceptibility and acceptability thresholds for colour differences in dentistry. *J Dent* 2014;42:637-44.
21. Vichi A, Louca C, Corciolani G, Ferrari M. Color related to ceramic and zirconia restorations: a review. *Dent Mater* 2011;27:97-108.
22. Habib SR, Shiddi IF. Comparison of shade of ceramic with three different zirconia substructures using spectrophotometer. *J Contemp Dent Pract* 2015;16:135-40.
23. Tabatabaian F, Taghizade F, Namdari M. Effect of coping thickness and background type on the masking ability of a zirconia ceramic. *J Prosthet Dent* 2018;119:159-65.
24. Vichi A, Fazi G, Carrabba M, Corciolani G, Louca C, Ferrari M. Spectrophotometric evaluation of color match of three different porcelain systems for all-ceramic zirconia-based restorations. *Am J Dent* 2012;25:191-4.
25. Harada R, Takemoto S, Hattori M, Yoshinari M, Oda Y, Kawada E. The influence of colored zirconia on the optical properties of all-ceramic restorations. *Dent Mater* 2015;34:918-24.
26. Sinmazisik G, Demirbas B, Tarcin B. Influence of dentin and core porcelain thickness on the color of fully sintered zirconia ceramic restorations. *J Prosthet Dent* 2014;111:142-9.
27. Sagirkaya E, Arıkan S, Sadık B, Kara C, Karasoy D, Cehreli M. A randomized, prospective, open-ended clinical trial of zirconia fixed partial dentures on teeth and implants: interim results. *Int J Prosthodont* 2012;25:221-31.
28. Dede DÖ, Armağancı A, Ceylan G, Celik E, Cankaya S, Yilmaz B. Influence of implant abutment material on the color of different ceramic crown systems. *J Prosthet Dent* 2016;116:764-9.
29. Carrillo de Albornoz A, Vignoletti F, Ferrantino L, Cárdenas E, De Sanctis M, Sanz M. A randomized trial on the aesthetic outcomes of implant-supported restorations with zirconia or titanium abutments. *J Clin Periodontol* 2014;41:1161-9.
30. Wang F, Takahashi H, Iwasaki N. Translucency of dental ceramics with different thicknesses. *J Prosthet Dent* 2013;110:14-20.
31. Sulaiman TA, Abdulmajeed AA, Donovan TE, Ritter AV, Vallittu PK, Närhi TO, et al. Optical properties and light irradiance of monolithic zirconia at variable thicknesses. *Dent Mater* 2015;31:1180-7.
32. 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.
33. Oh SH, Kim SG. Effect of abutment shade, ceramic thickness, and coping type on the final shade of zirconia all-ceramic restorations: in vitro study of color masking ability. *J Adv Prosthodont* 2015;7:368-74.
34. Shiraishi T, Watanabe I. Thickness dependence of light transmittance, translucency and opalescence of a ceria-stabilized zirconia/alumina nanocomposite for dental applications. *Dent Mater* 2016;32:660-7.
35. Jeong ID, Bae SY, Kim DY, Kim JH, Kim WC. Translucency of zirconia-based pressable ceramics with different core and veneer thicknesses. *J Prosthet Dent* 2016;115:768-72.
36. Tsiliagkou A, Diamantopoulou S, Papazoglou E, Kakaboura A. Evaluation of reliability and validity of three dental color-matching devices. *Int J Esthet Dent* 2016;11:110-24.
37. Kim-Pusateri S, Brewer JD, Davis EL, Wee AG. Reliability and accuracy of four dental shade-matching devices. *J Prosthet Dent* 2009;101:193-9.
38. Zhang Y. Making yttria-stabilized tetragonal zirconia translucent. *Dent Mater* 2014;30:1195-203.
39. Tabatabaian F. Color in zirconia-based restorations and related factors: A literature review. *J Prosthodont* 2018;27:201-11.

Corresponding author:

Dr Farhad Tabatabaian
 Department of Prosthodontics, School of Dentistry
 Shahid Beheshti University of Medical Sciences
 Daneshjoo Blvd
 Tehran 1983963113
 IRAN
 Email: f_tabatabaian@yahoo.com

Acknowledgments

The authors thank Mr Aliakbar Deghost for preparation of the laboratory specimens.

Copyright © 2018 by the Editorial Council for *The Journal of Prosthetic Dentistry*.
<https://doi.org/10.1016/j.prosdent.2018.02.022>