Original Article

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Masking ability of two ceramics with different thicknesses on various substrates

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Objective: The objective of this study was to examine the influence of material type, thickness, and substrate color on the masking ability of two ceramics on various substrates.

Materials and methods: In total, 36 disc-shaped specimens (15 mm in diameter × 0.5- and 1.0-mm thicknesses) were fabricated from lithium disilicate glass ceramic (IPS e.max Press, n = 6), high-translucent zirconia (Lava Plus, n = 6), and high-translucent zirconia with liner material (Lava Plus/Liner, n = 6). Contrast ratios were measured over white and black substrates. Color differences were measured over different substrates: white, black, metal, and resin composite shades A2, A3, and C4. White and A2 substrates were used as reference groups. Contrast ratio and color difference values were analyzed with linear regression ($P<0.05$).

Results: Contrast ratios in the IPS e.max Press group at 0.5 and 1.0 mm showed the highest values (0.73 ± 0.04 and 0.87 ± 0.01) when compared with those in the Lava Plus and Lava Plus/Liner groups. IPS e.max Press at both thicknesses showed the highest masking ability over various substrates. Higher contrast ratio and masking ability were significantly related to thicker material. Material type, thickness, and substrate were significantly related to masking ability.

Conclusion: Ceramic type, thickness, and substrate color are strongly associated with contrast ratio and masking ability, both of which increase as thickness increases.

Clinical implications: Increased ceramic thickness could benefit masking ability. For improved masking ability, IPS e.max Press is recommended over Lava Plus and Lava Plus/Liner for the masking of dark substrates.

Key words: contrast ratio, lithium disilicate ceramics, masking ability, zirconia ceramics

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Introduction

Over the years, ceramics have been increasingly used for the tooth-colored restoration of anterior teeth [1]. Many factors are involved in the final color of all-ceramic restorations, for example, thickness and translucency of the ceramic, color of the luting resin cement, and color of the supporting substrate [2-5]. The supporting substrate, such as a tooth or artificial materials, plays a major role in the final color of a ceramic restoration [2]. Previous studies have reported that the final color of a veneer was affected by the color of the supporting substrate [6]. The use of a dark or high-opacity substrate resulted in a detectable change of the final color after cementation when compared with that achieved with a light or low-opacity substrate [7]. The thickness of the material regulates its translucency [8,9]. In addition, luting resin cement also influences the final color of a restoration [10]. Therefore, matching the final color of all-ceramic restorations to that of natural teeth is still considered to be a difficult and largely subjective task [11]. Ceramic selection is considered to be crucial for optimization of the aesthetic outcome [1].

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The translucency of all-ceramics varies among selected systems and depends strongly on the amount of light-scattering, which is affected predominantly by their microstructure and thickness [8,9,12]. When compared with glass-based ceramics, zirconia is considered to be less translucent [13,14].

Contrast ratio (CR) is considered to be one method for measuring the translucency of all-ceramic systems and has been used in previous studies [15,16]. The relative opacity of ceramics can be measured by the differences between specimens over black and white backgrounds. The space system Y^{xy} was used to measure the contrast ratio as a ratio of reflectance (Y_b/Y_w), with the value from the specimen placed over a black background (Y_b) relative to the value from the specimen placed over a white background (Y_w). In contrast, when CR decreases, the translucency of the specimen increases [13,17,18].

The masking ability of all-ceramic systems can be measured by the color differences (ΔE) when the specimen is placed over different substrates. There will be no color difference ($\Delta E = 0$) if the masking ability is perfect [18]. A color difference in the range of 3.3 to 3.7 was considered to be clinically acceptable, as has been reported by one or more operators, while some studies reported higher values to be clinically acceptable [19, 20].

Previous studies reported that different types of materials and thicknesses resulted in different contrast ratios and levels of masking ability [2,5,6,21]. Unfortunately, none of the previous studies has reported the influence of association across material type, thickness, color of the substrate, and reference color on masking ability. This current study aimed to investigate the influence of material choice and associated variables on contrast ratio and masking ability. The null hypothesis in this study was that ceramic type, thickness, and substrate would have no significant effect on the material's masking ability.

IPS e.max Press and Lava Plus have been introduced as an alternative material for anterior restorative region in recent years. IPS e.max Press (lithium disilicate) represents level of translucency similar to natural tooth, while the ability of masking the color of the underlying substrate may not be as good as those made from zirconia. Lava Plus, the new version of zirconia, in addition with various liners, occupies a higher level of translucency as compared to its predecessors. However, the masking ability of the underlying dark substrate of Lava Plus is still questionable.

Therefore, High Opaque (HO) IPS e.max Press was chosen to compare with Lava Plus and shade MO liner among various substrates, in order to investigate material of choice for anterior restorative in terms of the ability to mask the underlying substrate color, while also to represent similar translucency with tooth structure in order to achieve optimum esthetic outcomes.

Materials and methods

In total, 36 disc-shaped specimens were fabricated from three types of ceramics: IPS e.max Press HO 0 ingot (Ivoclar Vivadent, Schaan, Liechtenstein), Lava Plus (3M ESPE, St. Paul, MN, USA), and Lava Plus/Liner shade MO W2 (3M ESPE). Each group consisted of 12 specimens based on material type and was further divided into two groups (n = 6) according to thickness (0.5 or 1.0 mm), yielding a total of six groups. A *post hoc* power analysis revealed, on the basis of the mean, a between-groups comparison effect size in the present study (d = 0.91).

The specimens were tested over six substrates: white, black, metal, and resin composite shades A2, A3, and C4 (Z350; 3M ESPE). A spectrophotometer (Ultrascan XE, HunterLab, Reston, VA, USA) with a wavelength range from 360 to 750 nanometers and a view area size of 9.53 mm was used in this study for color measurement.

Fabrication of ceramic specimens

Plastic sheets of 0.5 mm and 1.0 mm were cut into circular discs of 15 mm diameter by means of a heated metal pipe. The specimens were fabricated by the lost wax technique according to the manufacturer's instructions and were later subjected to air abrasion with two bars of 50 μm aluminum oxide (Renfert GmbH, Hilzingen, Germany) and cleansed ultrasonically (IPS e.max Press Invex liquid; Ivoclar Vivadent) (Figure 1). The ceramic specimens were immersed in distilled water at 37°C ± 1°C for 24 h and polished with 600-, 800-, 1000-, and 1200-grit abrasive papers (Figure 1).

The pre-sintered blocks of Lava Plus were cut into discs of 18 mm diameter with thicknesses of 0.6 mm and 1.2 mm to compensate for 20% shrinkage. After being sintered, the Lava Plus specimens were immersed in distilled water at 37°C ± 1°C for 24 h, then polished with aluminum oxide paper (3M ESPE) of 320, 500, and 1000 grit.

Five measurements were made at five different locations around the center of each disc with a Praecimeter (Aura-Dental GmbH, Aura an der Saale, Germany) to confirm the thickness at 0.5 ± 0.05 mm or 1.0 ± 0.05 mm. All ceramic specimens were immersed in distilled water at 37°C ± 1°C for 24 h before color measurement.

Fabrication of backgrounds

Five different substrates of 37.80-mm diameter and 1.94-mm thickness were studied: white, black, metal, and shades A2, A3, and C4 of resin composite. White and A2 substrates were used as reference groups.

A metal substrate was cast from non-precious metal and sandblasted with two bars of 50-μm aluminum oxide (Renfert GmbH) to eliminate shininess and simulate a metal post in endodontically treated teeth.

To simulate dentin color, the substrates of resin composite shades were fabricated with a metal substrate as a reference. Vinylpolysiloxane (VPS) putty (Variotime, Heraeus, Germany) and light silicone (Silagum, DMG, Hamburg, Germany) were used as duplication materials. Resin composite was preheated to facilitate flow into the silicone mold. It was then pressed onto a glass slab and light-cured with a visible-light-polymerization unit (Demi Plus, Kerr Corporation, Orange, CA, USA) at 750 mW/cm^2 for 40 s. To prevent penetration of excess light, additional resin composite of 15 mm in diameter and 1.0 mm in thickness was added to the specimen. Clear resin compensated for the excess circumferential space around the specimen.

All resin composite substrates were polished under water coolant in an automatic polishing machine (DPS 3200, IMTECH, Durban, South Africa) with 600-, 800-, 1000-, and 1200-grit abrasive papers. The substrates were immersed in distilled water at 37°C ± 1°C for 24 h before color measurement.

Spectrophotometric analysis

Color measurements of all Lava Plus samples were performed by spectrophotometer (Ultrascan XE, HunterLab). Then, Lava Ceram liner shade MO W2 was applied to the discs with 0.1mm thickness, according to the manufacturer's recommendations, and the color difference was measured again.

Before each measurement, the spectrophotometer was calibrated with standard black and white substrates according to the manufacturer's instructions. First, the white control substrate was used as a control group. Later, A2 substrate was used as a control group against black, metal, A3, and C4 substrates, to simulate the colors of natural teeth. Measurements were done for each specimen with various substrates. The equation $\Delta E^*_{ab} = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{½}$ was used to calculate the color differences between and among groups.

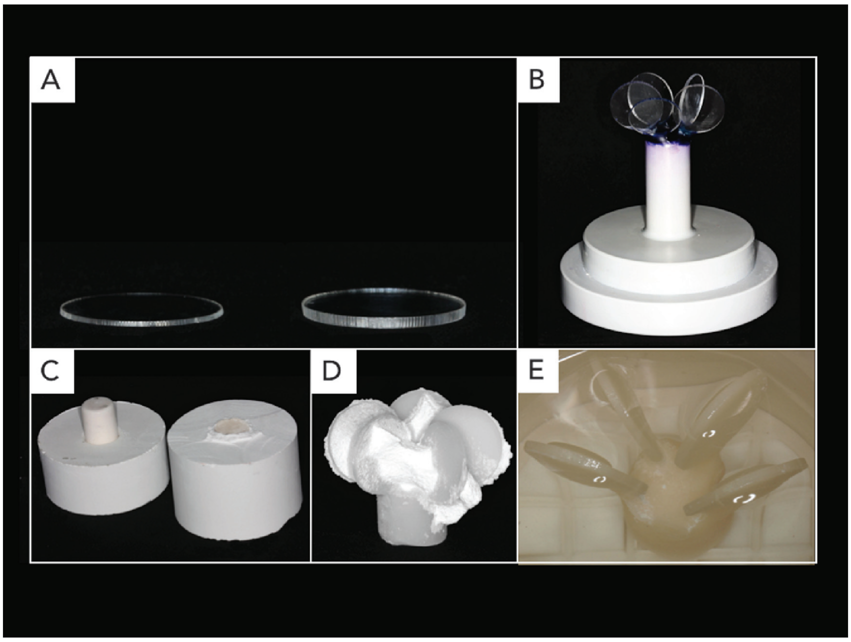

Figure 1. Plastic sheets with thicknesses of 0.5 mm and 1.0 mm and diameter of 15 mm (A). Plastic sheets were attached to a ring mold with sprue (B). Investment was removed with a carborundum disc (C). Remaining investment was sandblasted with aluminum oxide (D) and ultrasonically cleansed with IPS Invex Press liquid (E).

Statistical analysis

The data were analyzed by STATA software, version 10. Multiple linear regression analysis was used to determine if any correlation of contrast ratio and masking ability existed among ceramic type, thickness, and substrate. The level of significance was determined at 5% ($P<0.05$).

Results

Contrast ratio

As shown in Figure 2, specimens in the IPS e.max Press group presented the highest mean contrast ratio at 0.5 and 1.0 mm thicknesses. In addition, the study found that the contrast ratio of specimens in the Lava Plus/Liner group was comparable with that of those in the Lava Plus group and lower than that in those of the IPS e.max Press group. In terms of thickness, the 1.0-mm-thickness sample revealed a contrast ratio higher than that of the 0.5-mm-thickness sample.

The analyses of the associations between and among contrast ratio, masking ability and material type, thickness, substrate, and reference group are shown in Table 1. With regard to thickness, higher contrast ratios were significantly related to thicker material ($P = 0.05$). Ceramics with a thickness of 1.0 mm showed significantly higher contrast ratios than did 0.5-mm specimens. In addition, mean contrast ratios of specimens in the IPS e.max Press group revealed significantly higher contrast ratios than those in the other groups.

Masking ability

With respect to masking ability, the mean color difference values (ΔE) were likely to be lowest in the IPS e.max Press group, followed by the Lava Plus/Liner group, and were highest in the Lava Plus group (Table 2). In terms of thickness, 1.0-mm-thickness samples were significantly correlated with lower color difference values when compared with the 0.5-mm-thickness samples (Table 1). In addition, regarding the substrate color with A2 as a reference, A3, C4, metal, and black were less likely to show color difference values. In comparison, with white as a reference, A2, A3, C4, metal, and black, the color difference values were more likely to be higher (P = 0.05).

In this study, we found that the color difference values were significantly related to substrate shade. The A3 substrate revealed the significantly lowest color difference values, followed by C4, metal, and black substrates. In addition, the reference group of A2 substrate presented significantly lower color difference values when compared with the white substrate (P = 0.05).

Discussion

In our study, the findings showed that specimens in the IPS e.max Press group presented with significantly higher contrast ratio values than those in the Lava Plus/Liner and Lava Plus groups. In addition, contrast ratio values were strongly correlated with color difference values. As thickness increases, both contrast ratio and color difference values decrease. The findings in this study are also consistent with those of previous studies that reported strong correlation between contrast ratios and masking ability [22,23]. Lava Plus tended to exhibit more translucency when compared with previous Lava materials. Moreover, the liner applied to the Lava Plus ceramic exhibited low opacity, which explained the results showing no significant differences between the Lava Plus/Liner and Lava Plus groups. In addition, IPS e.max Press and Lava Plus samples in this study had no color impregnated into the materials. Meanwhile, a previous study reported that a colored zirconia framework with proper veneering material showed increased masking ability over an underlying dark substrate [24]. Color difference values increase as material changes from IPS e.max Press to Lava Plus/Liner and Lava respectively. In addition, color difference values decrease as substrate changes from black to metal and resin composite shade respectively.

All three ceramic groups in this study demonstrated the strong influence of thickness on increasing contrast ratios, in agreement with the results of previous studies [12,17,25,26]. The findings of this study are also consistent with those of other studies suggesting that thickness and contrast ratios demonstrated a direct linear relationship [6,27,28].

In this study, we found that IPS e.max Press tended to have the highest degree of masking

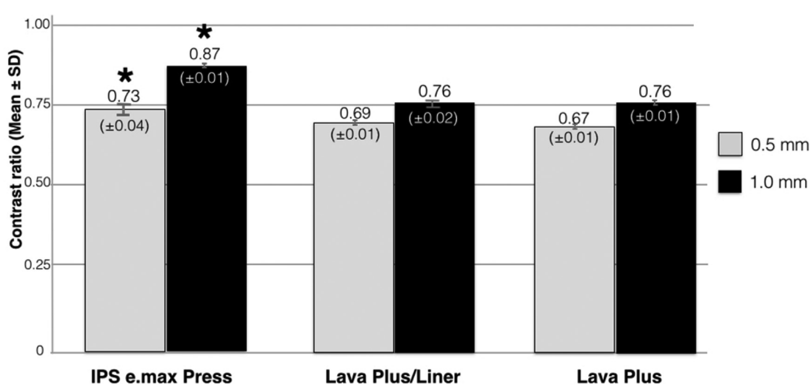

Figure 2. Graph showing mean contrast ratio values for all ceramic specimens.

Table 1. Association of (A) contrast ratio, (B) color difference values (ΔE), and (C) underlying variables (material, thickness, substrate, reference group)

Variables (= 1 if yes, = 0 if no)	Beta coefficients (95% CI)	Unadjusted Odds ratios	Adjusted Odds ratios	P Value
A.) Contrast Ratio				
Material				
- Lava Plus	-8.28	(-13.07, -3.48)	(-10.29, -6.26)	0
- Lava Plus/Liner Lava Ceram	-7.38	(-12.18, -2.59)	(-9.39, -5.37)	0
- IPS e.max Press (as reference)				
Thickness				
- 0.5 mm	-10.06	(-13.09, -7.03)	(-11.70, -8.42)	0
- 1.0 mm (as reference)				
B.) Color difference value by white substrate				
Material				
- Lava Plus	2.4	(1.61, 3.20)	(2.14, 2.67)	0
- Lava Plus/Liner Ceram	1.65	(.86, 2.44)	(1.38, 1.92)	0
- IPS e.max Press (as reference)				
Thickness				
- 0.5 mm	3.36	(2.86, 3.87)	(3.15, 3.58)	0
- 1.0 mm (as reference)				
Substrates				
- Metal	-1.27	(-2.25, -.28)	(-1.61, -.92)	0
- A2	-3.04	(-4.03, -2.06)	(-3.39, -2.70)	0
- A3	-3.13	(-4.11, -2.14)	(-3.47, -2.79)	0
- C4	-2.33	(-3.31, -1.34)	(-2.67, -1.98)	0
- Black (as reference)				
B.) Color difference value by A2 substrate				
Material				
- Lava Plus	0.62	(.11, 1.13)	(.41, .84)	0
- Lava Plus/Liner Ceram	0.26	(-.25, .77)	(.04, .47)	0.019
- IPS e.max Press (as reference)				
Thickness				
- 0.5 mm	.75	(.34, 1.16)	(.57, .93)	0
- 1.0 mm (as reference)				
Substrates				
- Metal	-1.26	(-1.58, -.93)	(-1.50, -1.01)	0
- A3	-2.79	(-3.11, -2.46)	(-3.03, -2.54)	0
- A4	-2.39	(-2.71, -2.06)	(-2.64, -2.14)	0
- Black (as reference)				

Table 2. Distribution of color difference value (ΔE), (mean±SD)across difference materials, thickness, and substrate

		Mean (±SD) color difference values by various substrates									
Materials	Thickness (mm)	Black		Metal		A2		A3		C4	
		Reference substrate		Reference substrate		Reference substrate		Reference substrate		Reference substrate	
		White	A2	White	A2	White	A2	White	A2	White	A2
IPS e.max Press	0.5	11.64±0.84	3.45±0.81	10.31±0.60	2.20±0.42	8.54±0.46	-	8.26±0.40	0.74±0.73	9.12±0.46	1.04±0.48
	1.0	5.61±0.29	1.54±0.22	5.08±0.27	1.04±0.20	4.23±0.28	-	4.22±0.29	0.49±0.30	4.64±0.29	0.66±0.28
Lava Plus/ Liner	0.5	12.48±0.50	3.90±0.42	10.98±0.51	2.39±0.37	8.83±0.52	-	8.62±0.42	0.58±0.34	9.71±0.44	0.97±0.43
	1.0	9.29±0.16	2.73±0.11	8.07±0.28	1.52±0.17	6.71±0.29	-	6.39±0.31	0.58±0.12	7.09±0.13	0.55±0.22
Lava Plus	0.5	13.61±0.28	4.77±0.24	11.89±0.27	3.02±0.24	9.20±0.57	-	9.44±0.34	0.39±0.27	10.35±0.52	1.30±0.41
	1.0	10.04±0.34	3.38±0.30	8.90±0.21	2.06±0.18	7.04±0.32	-	7.10±0.23	0.27±0.14	7.95±0.22	0.93±0.22

ability, followed by Lava Plus/Liner and Lava Plus. The color differences in Lava Plus/Liner and Lava Plus also showed significant differences in masking ability. This result could be explained by the increased thickness of Lava Plus after liner was applied. In addition, the liner conferred slight opacity, which influenced masking ability on the underlying substrates. Therefore, we can assume that the liner was responsible for the increased masking ability.

In addition, thickness is one of the factors that influence masking ability. Samples with 1.0-mm thickness tended to have higher masking ability than those with 0.5-mm thickness. This was probably a simple direct result of the increased 0.5-mm distance that light must penetrate [29]. Moreover, substrate color also influenced final color perception: every substrate but the A2 and A3 showed color difference values that differed significantly from each other.

Translucency reinforces natural tooth characteristics. A low-translucency material is able to mask underlying dark backgrounds but might not create natural tooth characteristics. To achieve ideal esthetic outcomes, restorative materials should have proper opacity that can mask the underlying substrate color and offer optimum translucency to represent that of the teeth [30]. Therefore, the core material should be chosen carefully, since it affects the final color outcome [31].

The clinically acceptable color difference in dentistry ranges from 3.3 to 3.7 [18-20,32]. In this study, the smallest color difference of samples over a black substrate, with white substrates as a reference group, was 5.61, which is worse than the clinically acceptable value. The results revealed that none of the materials tested was able to mask the underlying dark substrate in the clinically acceptable range when a white substrate was used as the reference. In contrast, when A2 was used as a reference, the results showed that the color difference values of all materials tested at 0.5- and 1.0-mm thickness over metal substrate were in the clinically acceptable range. In addition, in 1.0-mm-thick samples over black substrates, the color difference values of IPS e.max Press and Lava Plus/Liner exceeded the clinically acceptable range. The materials tested in this study showed lower color difference values when A2 was used as a control substrate, compared with the white control group. The results showed that samples over yellowish substrates had a high tendency to lower color difference values when compared with those over white substrates. The possible explanation for the results could be that the A2 substrate exhibits yellowish pigment, while white substrate has no color impregnated. Therefore, color difference values between control groups were drastically changed when the substrate was changed from white to A2 substrate. In addition, optimum thickness of both IPS e.max Press and Lava Plus with or without liner under C4 substrate were all capable to mask the underlying substrate color in clinically acceptable range. Both A2 and C4 shades exhibit yellow pigments. Consequently, the results show slight difference in number on C4 substrate when A2 was used as a control group.

It is important to take into account the limitations of ceramics in masking ability, in terms of influencing factors. The first issue to be considered is that different materials have different microstructures and masking abilities. Second, a thicker material tends to have a higher degree of masking ability than a thinner material. In addition, substrates also play an important role in the final color outcome. Further, to achieve optimum esthetic outcomes, interactions between and among factors should be strongly considered. Finally, a yellowish substrate contributes a higher degree of masking ability when compared with a white substrate.

Therefore, within the limitations of this study, the following conclusions can be drawn:

1. The factors ceramic type, thickness, and substrate color had a strong influence on the

masking ability of lithium disilicate and zirconia ceramics.

2. A higher masking ability of the ceramic was significantly related to its thickness.

3. A darker substrate color was significantly related to a lower masking ability of ceramics when compared with that achieved with a lighter-color substrate.

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References

1. Kelly JR, Nishimura I, Campbell SD. Ceramics in dentistry: historical roots and current perspectives. *J Prosthet Dent* 1996; 75: 18-32.
2. Shono NN, Al Nahedh HN. Contrast ratio and masking ability of three ceramic veneering materials. *Oper Dent* 2012; 37: 406-416.
3. Bichacho N. Porcelain laminates: integrated concepts in treating diverse aesthetic defects. *Pract Perio Aesthet Dent* 1995; 7: 13-23.
4. Calamia JR, Calamia CS. Porcelain laminate veneers: reasons for 25 years of success. *Dent Clin North Am* 2007; 51: 399-417.
5. Li Q, Yu H, Wang YN. Spectrophotometric evaluation of the optical influence of core build-up composites on all-ceramic materials. *Dent Mater* 2009; 25: 158-165.
6. Azer SS, Rosenstiel SF, Seghi RR, Johnston WM. Effect of substrate shades on the color of ceramic laminate veneers. *J Prosthet Dent* 2011; 106: 179-183.
7. Chaiyabutr Y, Kois JC, Lebeau D, Nunokawa G. Effect of abutment tooth color, cement color, and ceramic thickness on the resulting optical color of a CAD/CAM glass-ceramic lithium disilicate-reinforced crown. *J Prosthet Dent* 2011; 105: 83-90.
8. Heffernan MJ, 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.
9. Seghi RR, Johnston WM, O'Brien WJ. Spectrophotometric analysis of color differences between porcelain systems. *J Prosthet Dent* 1986; 56: 35-40.
10. 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: 179-186.
11. Wee AG, Monaghan P, Johnston WM. Variation in color between intended matched shade and fabricated shade of dental porcelain. *J Prosthet Dent* 2002; 87: 657-666.
12. Brodbelt RH, O'Brien WJ, Fan PL. Translucency of dental porcelains. *J Dent Res* 1980; 59: 70-75.
13. Heffernan MJ, 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.
14. Chen YM, Smales RJ, Yip KH, Sung WJ. Translucency and biaxial flexural strength of four ceramic core materials. *Dent Mater* 2008; 24: 1506-1511.
15. Johnston WM. Review of translucency determinations and applications to dental materials. *J Esthet Restor Dent* 2014; 26: 217-223.
16. Seghi RR, Hewlett ER, Kim J. Visual and instrumental colorimetric assessments of small color differences on translucent dental porcelain. *J Dent Res* 1989; 68: 1760-1764.
17. Antonson SA, Anusavice KJ. Contrast ratio of veneering and core ceramics as a function of thickness. *Int J Prosthodont* 2001; 14: 316-320.
18. Chu FC, Chow TW, Chai J. Contrast ratios and masking ability of three types of ceramic veneers. *J Prosthet Dent* 2007; 98: 359-364.
19. Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. *J Dent Res* 1989; 68: 819-822.
20. Ruyter IE, Nilner K, Møller B. Color stability of dental composite resin materials for crown and bridge veneers. *Dent Mater* 1987; 3: 246-251.
21. 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.
22. Chu FC, Sham AS, Luk HW, Andersson B, Chai J, Chow TW. Threshold contrast ratio and masking ability of porcelain veneers with high-density alumina cores. *Int J Prosthodont* 2004; 17: 24-28.
23. Barizon KTL, Vargas MA, Qiand F, Cobb DS, Gratton DG, Geraldeli S. Ceramic materials for porcelain veneers. Part I: Correlation between translucency parameters and contrast ratio. *J Prosthet Dent* 2013; 110.

24. Aboushelib MN, Dozic A, Liem JK. Influence of framework color and layering technique on the final color of zirconia veneered restorations. ***Quintessence Int*** 2010; 41: e84-e89.
25. Yaman P, Qazi SR, Dennison JB, Razzoog ME. Effect of adding opaque porcelain on the final color of porcelain laminates. ***J Prosthet Dent*** 1997; 77: 136-140.
26. Yu B, Lee Y-K. Measurement of translucency of tooth enamel and dentin. ***Acta Odontol Scand*** 2009; 67.
27. O'Keefe KL, Pease PL, Herrin HK. Variables affecting the spectral transmittance of light through porcelain veneer samples. ***J Prosthet Dent*** 1991; 66: 434-438.
28. Ozturk O, Celik VG. The effect of ceramic thickness and number of firings on the color of two all-ceramic systems. ***J Prosthet Dent*** 2009; 100.
29. Ilie N, Stawarczyk B. Quantification of the amount of light passing through zirconia: the effect of material shade, thickness, and curing conditions. ***J Dent*** 2014; 42: 684-690.
30. Fabbri G, Mancini R, Marinelli V, Ban G. Anterior discolored teeth restored with procera all-ceramic restorations: a clinical evaluation of the esthetic outcome based on the thickness of the core selected. ***Eur J Esthet Dent*** 2011; 6: 76-86.
31. Kim JH, Kim KB, Kim WC, Kim HY, Kim JH. Evaluation of the color reproducibility of all-ceramic restorations fabricated by the digital veneering method. ***J Advanced Prosthod*** 2014; 6: 71-78.
32. Vichi A, Ferrari M, Davidson CL. Color and opacity variations in three different resin-based composite products after water aging. ***Dent Mater*** 2004; 20: 530-534.