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Contrast Ratio and Masking Ability of Three Ceramic Veneering Materials

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Clinical Relevance

Masking severely discolored dentitions is one of the indications for the use of ceramic veneers. IPS e.max Press and Vita VM7 had significantly higher contrast ratios and masking abilities than Nobel Rondo Press Alumina: Solo. However, none of the materials tested was able to completely mask the black background.

SUMMARY

Statement of the Problem: Porcelain veneer materials are translucent and are therefore affected by their thickness as well as the color of the underlying substructure, which limits their masking ability and compromises the esthetic result in heavily stained teeth.

Purpose: The purpose of this study was to compare the contrast ratio (CR) and masking ability of three different veneering ceramics with two thicknesses by measuring the color differences over white and black backgrounds. Correlations between CR and masking ability of these veneering ceramics were evaluated.

Methods and Materials: A total of 30 disc-shaped specimens (12 mm diameter × 1.0 mm or 1.5 mm) were fabricated in shade A2 from three types of all-ceramic systems: IPS e.max Press (IPSe; Ivoclar Vivadent, Schaan, Liechtensein), Vita VM7 (VM7; VITA Zahnfabrik, Bad Säckingen, Germany), and Nobel Rondo Press Alumina: Solo (NRPA; Nobel Biocare, Zürich-Flughafen, Switzerland). The CR, defined as the ratio of illuminance (Y) of the test material when placed on the black background (Yb) to the illuminance of the same material when placed over a white background (Yw), was determined (CR=Yb/Yw). The color (CIE L*a*b*) and Y of each specimen were measured over standard white and black tiles using a spectrophotometer (ColorEye 7000 A, Model C6, GretagMacbeth, New Windsor, NY, USA). Masking abilities of the specimens were determined by measuring the color difference (ΔE) over white and black backgrounds. Both CR and ΔE data were analyzed using two-way analysis of variance (ANOVA). One-way ANOVA was used to compare the mean values of CR across the three materials followed by the Duncan multiple comparison test. The correlations between CR and ΔE were determined by comparing R^2 values obtained from a linear regression analysis. A Student *t*-test for inde-

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pendent samples was used to compare the mean contrast ratio and ΔE values for the two thicknesses.

Results: CR values of NRPA were significantly less than those of IPSe and VM7, and the CR of IPSe was higher than that of VM7. Furthermore, CR increased as the thickness of the discs increased to 1.5 mm for all three materials. Mean ΔE values were significantly higher with 1.0-mm-thick discs than with 1.5-mm discs. Among the three materials it was observed that NRPA had the highest ΔE when compared with IPSe or VM7, whereas the ΔE of the latter two were not significantly different from one another. There was a strong linear correlation between CR and masking ability.

Conclusion: CR and masking ability are affected by the type as well as the thickness of the ceramic used. IPSe and VM7 are similar in their masking abilities, whereas NRPA had the lowest masking ability. NRPA was the most translucent, followed by VM7; IPSe was the most opaque. None of the materials tested was able to completely mask the black background. It is therefore recommended that the type of ceramic should be chosen according to each clinical situation.

INTRODUCTION

Over the past decade ceramic restorations have become increasingly popular despite some of their shortcomings, including brittleness, catastrophic failure, and wearing of opposing teeth. Their popularity is attributed to their superior esthetic properties, biocompatibility, and longevity.[1–3] Porcelain veneers are perceived to be one of the most conservative means of restoring unesthetic anterior teeth. Their indications include discoloration, tetracycline staining, fluorosis, diastema closure, and malformed and malpositioned teeth.[4–7] Veneers go as far back as the late 1930s, where they were temporarily used by actors during filming; at that time adhesive systems did not exist, and therefore long-term retention was not possible.[8] Adhesive retention of veneers was later demonstrated by Calamia, Simonsen, and Horn in the early 1980s by using hydrofluoric acid etching in combination with silane coupling agents.[5,6,9]

The final color of the veneer depends on three chief elements and their interaction with one another. These elements are the color of the tooth/substructure, the thickness and type of ceramic material used, and the resin cement selected. Combining the three is the means by which an optimal esthetic outcome can be realized.[10–13]

The evidence within the literature indicates that masking of heavy stains such as fluorosis and tetracycline discoloration requires the use of opaquers, opaque luting cements, or tints.[14–19] Another approach is the use of opaque cores, including alumina or zirconia substructure.[15,19–21] When that is done, the resulting veneer becomes opaque and lifeless and esthetics is compromised.[15,20]

The other possible solution to the problem of heavily stained teeth is to increase the thickness of the veneer from the standard 0.75-mm thickness to 1.0–1.5 mm because it appears that the thickness of the material influences its opacity, which in turn may increase its masking ability. Further reduction of the labial and interproximal surfaces may provide additional space for the veneer, which allows more leeway for color correction,[17,20,22] but this might result in dentine exposure and consequent sensitivity after cementation. However, it was observed that within two weeks sensitivity disappeared.[17]

Contrast ratio (CR) is one of the methods used to compare opacity of all ceramic systems. Differential colorimetric assessment of the ceramic materials on white and black backgrounds may be used to measure the relative opacity of dental porcelain. CR can be computed from the Y*xy* color space system measurements as the ratio of reflectance (Yb/Yw) when the specimen is placed on a black tile (Yb) relative to that obtained when the specimen is placed on a white tile (Yw). The values of the hue (x), chroma (y), and luminous intensity (Y) can be obtained from spectrophotometric measurements as well as colorimetric measurements.[23–25]

Chu and others[25] compared the masking ability and CRs of 0.7-mm-thick ceramic veneers and found that Vitadur Alpha had the lowest CR and poorest masking ability as compared with Procera and Empress II. In addition, they concluded that the use of both Procera and Empress II as veneering materials may be limited when heavily discolored teeth are involved because they were not fully capable of masking a black background.

The effect of porcelain opacity on the final shade of 0.7-mm-thick veneers cemented to dark substrates was evaluated by Davis and others.[26,27] Their results showed that the veneers provided a masking effect; however, the resultant color of the veneer-substrate system will not be that of the porcelain or the substrate. Furthermore, the translucency of the porcelain is as influential to the final result as the color of the substrate. Similar results were reached by Yaman and others[28] when researching the effect of adding opaque porcelain on the final color of porcelain veneers.

Vichi and others[29] studied the effect of different opaque posts on the masking ability of IPS Empress leucite-reinforced ceramic of various thickness (1.0, 1.5, or 2.0 mm) and noted that the ceramic restoration was not affected by the different substructures when its thickness was 2.0 mm.

CRs of six different core ceramics (ie, IPS Empress, IPS Empress II, In-Ceram Alumina, In-Ceram Spinell, In-Ceram Zirconia, and Procera All-Ceram) were compared by Heffernan and others (2002). The authors ranked these materials' CRs in order of decreasing translucency as follows: In-Ceram Spinell > Empress, Procera, Empress II > In-Ceram Alumina > In-Ceram Zirconia.[24] In part II of that study, the authors compared the translucency of these ceramic systems when veneered with their respective porcelains and after glazing. Significant differences in CR were found among these ceramic systems, and a range of translucency was established for the veneered all-ceramic systems. Such variety may ultimately affect the ability of the ceramics to match the natural tooth. In addition, the glazing cycle resulted in decreased opacity for all materials tested, with the exception of the opaque In-Ceram Zirconia and metal-ceramic specimens.[30]

The purpose of the present study was to compare the CR (opacity) and masking ability of three different veneering ceramics: IPS e.max Press (IPSe; Ivoclar Vivadent, Schaan, Liechtensein), Vita VM7 (VM7; VITA Zahnfabrik, Bad Säckingen, Germany), and Nobel Rondo Press Alumina: Solo (NRPA; Nobel Biocare, Zürich-Flughafen, Switzerland) with two thicknesses (1.0 and 1.5 mm) by measuring the color differences over white and black backgrounds. In addition, this study tested the correlation between the CR and the masking ability of these veneering ceramics.

The null hypothesis of this study was that there would be no significant difference in the masking ability and CR of the ceramics tested and between the different thicknesses of these materials. In addition, there would be no correlation between the CR and the masking ability of the three materials.

MATERIALS AND METHODS

A total of 30 disc-shaped specimens were fabricated in shade A2 from three types of all-ceramic systems: IPSe (Ivoclar Vivadent), VM7 (VITA Zahnfabrik), and NRPA (Nobel Rondo). The discs were 12.0 mm in diameter and 1.0 mm or 1.5 mm thick. All discs were constructed using stainless steel molds that were custom made to meet the desired diameter and thickness (Figure 2).

IPSe offers lithium disilicate glass ceramic ingots for the press technique. These ingots have been developed on the basis of a lithium silicate glass ceramic. Five 1.0 mm- and five 1.5-mm-thick discs were fabricated as recommended by the manufacturer using lost wax and heat-pressed techniques. One firing cycle at 700°C was accomplished in a calibrated furnace (EP 600, Ivoclar Vivadent). Later, the discs were immersed in IPSe Invex liquid (<1% hydrofluoric acid, Ivoclar Vivadent) and cleaned in an ultrasonic cleaner (NEY, Dentsply International, York, PA, USA), then subjected to airborne-particle abrasion using 50 μm aluminum oxide powder at 2 bar pressure (BEGO, ZiroDent Dentalhandel GbR, Cologne, Germany). A staining technique was used for the IPSe. Finally, etching of the discs was done using IPS etching gel for 20 seconds.

A layering technique was used in the fabrication of the 1.0- and 1.5-mm-thick VM7 discs, where every 2.1 g of powder were mixed with 1 mL of liquid. One dentin and two enamel ceramic layers were fired at 200°C-910°C in three firing cycles. The discs were etched with 10% hydrofluoric acid for 90 seconds.

NRPA was provided as pellets or ingots with 1 cm diameter and 9 mm thickness. Discs of 1.0- and 1.5-mm thickness were fabricated using lost wax and pressing techniques with two firing cycles at 890°C-900°C (EP 600, Ivoclar Vivadent). Etching with 5%

Figure 1. *Ceramic disk 1.5 mm thick and 12 mm in diameter.*

Figure 2. *Custom made stainless steel mold.*

hydrofluoric acid for four minutes was done to produce a rough surface for adhesive bonding.

All laboratory procedures were carried out to duplicate regular laboratory procedures of finishing, glazing, and etching. The specimens were finished using 400-grit waterproof silicon carbide abrasive papers under running water until the desired thickness was confirmed with a digital caliper (Model 193-111, Mitutoyo Mfg Co, Kawasaki, Japan). Afterward all specimens were cleaned in an ultrasonic bath (Ultrasound Vita-Sonic II, Vita Zahnfabrik, Germany) for five minutes and dried before spectrophotometric measurements were taken.

For each of the ceramic discs, three measurements were made in three different locations around the center of the disc. Therefore, the number of measurements used for statistical analysis was 15 (n=15) for each thickness investigated.

A spectrophotometer (ColorEye 7000 A, Model C6, GretagMacbeth, New Windsor, NY, USA) was used with an aperture of 0.12 × 0.31 inches, alongside ProPallette Gold Color Matching software version 3.1 (GretagMacbeth). This instrument measures the spectral reflectance of a color and converts it into a tristimulus value; it has a spectral range of 360 to 750 nm. The spectrophotometer CIE L*a*b* output is based on D65 illuminant. In CIE L*a*b* colorimetry, the color of an object is defined in a three-dimensional color space expressed in three coordinates: L* represents brightness (white-black), a* is for redness-greenness, and b* is for yellowness-blueness. The illuminance (Y) and color (CIE L*a*b*) of each specimen were measured over standard white and black tiles. The average values of the three measurements were taken. The instrument was calibrated using the white ceramic calibration tile and the zero calibration standard (black). As recommended by the manufacturer, calibration was done before measurements of each group (n=15) were taken or every eight hours. The Y value in Yxy color space represents the illuminance, where x is the value of hue and y is the value of chroma. The opacity of the specimen in terms of CR (CR=Yb/Yw) is defined as the ratio of illuminance of the test material when it is placed on the black background (Yb) to the illuminance of the same material when it is placed over a white background (Yw). Masking abilities of the specimens were determined by measuring the ΔE over white and black backgrounds.

The following equation was used:

$$\Delta E^* = [(L_1^* - L_0^*)^2 + (a_1^* - a_0^*)^2 + (b_1^* - b_0^*)^2]^{1/2}$$

$\mathrm{L}_1^*, \mathrm{a}_1^*, \mathrm{b}_1^*$ = Color of the specimens over the white background.

$\mathrm{L}_0^*, \mathrm{a}_0^*, \mathrm{b}_0^*$ = Color of the specimens over the black background.

Statistical Analysis

The data were analyzed using statistical software (SPSS, Version 16.0, SPSS Inc, Chicago, IL, USA). Differences among the CRs and masking abilities of the three materials with the two thicknesses were calculated using two-way analysis of variance (ANOVA). One-way ANOVA was used to compare the mean values of CR across the three materials followed by the Duncan multiple comparison test. The correlation between CR and masking ability was determined by comparing R^2 values obtained from a linear regression analysis. A Student t-test for independent samples was used to compare the mean CR and color difference values for the two thicknesses.

RESULTS

Contrast Ratio

Table 1 shows the mean percentages and corresponding standard deviations (SD) of the CR (opacity) of all ceramic specimens with the two different thicknesses as determined by the spectrophotometer. A Student t-test demonstrated that CR increased as the thickness of the discs increased to 1.5 mm for

Table 1. *The Results of Multiple Comparisons Test of Mean Contrast Ratio Percentages among and within Groups and the Student's t-test Comparison of the Mean Contrast Ratio for the Two Thicknesses*

Material	Thickness (mm)		t-test Sig
	1.0	1.5	
IPSe	0.78 (0.28) [a]	0.88 (0.12) [b]	.0001
NRPA	0.63 (0.42) [c]	0.71 (0.31) [d]	.0001
VM7	0.79 (0.09) [e]	0.85 (0.15) [f]	.0001

The mean difference is significant at the .05 level.
Different letters indicate significant differences.

all three materials, which indicates that opacity of these ceramic materials increases as their thicknesses increase.

It was observed that the CRs of NRPA were significantly less than those of IPSe and VM7 while the CR of IPSe was higher than that of VM7. This means NRPA was the least opaque, followed by VM7 while IPSe was the most opaque.

Two-way ANOVA showed that there was a significant material effect, thickness effect, and material-thickness interaction (p=0.0001), thereby rejecting the null hypothesis that stated there would be no significant difference in the CRs of the ceramics tested and between the different thicknesses of these materials (Table 2).

Masking Ability

Table 3 shows the mean values and corresponding SDs of the color parameters and masking ability of all ceramic specimens with the two different thicknesses as determined by the spectrophotometer. The results of the t-test for the two thicknesses are shown as well.

Table 2: *Two-way ANOVA Results for Comparison of Contrast Ratio Percentages*

	Sum of Square	df	Mean Square	F	Sig
Material	4521.235	2	2260.617	335.898	.0001
Thickness	1258.749	1	1258.749	187.033	.0001
Material x Thickness	167.903	2	83.951	12.474	.0001

Table 3: *Mean Values and SDs of ΔL*, Δa*, Δb* and ΔE (Masking Ability) for all Ceramic Specimens Corresponding to the Two Thicknesses*

Material	Color Coordinates	Ceramic thickness (mm)		t-test Sig
		1.0	1.5	
IPSe	ΔL*	5.24 (1.18)	2.4(0.49)	.0001
	Δa*	1.51 (0.11)	1.25 (0.15)	.0001
	Δb*	5.80(0.93)	3.46 (0.66)	.0001
	ΔE	8.03 (1.26)	4.42 (0.81)	.0001
NRPA	ΔL*	9.01 (3.31)	5.41 (1.52)	.0001
	Δa*	0.76 (0.10)	0.65 (0.07)	.002
	Δb*	5.37 (1.25)	3.86 (0.67)	.0001
	ΔE	10.88 (2.15)	6.81 (1.04)	.0001
VM7	ΔL*	4.96 (0.49)	3.65 (0.56)	.0001
	Δa*	1.68 (0.09)	1.61 (0.09)	.035
	Δb*	5.18 (0.36)	4.18 (0.46)	.0001
	ΔE	7.39 (0.5)	5.81 (0.65)	.0001

The mean difference is significant at the .05 level.

Generally, the ΔL*, Δa*, and Δb* values decreased as the thickness of the ceramic discs increased from 1.0 to 1.5 mm. For the IPSe and NRPA, the ΔL*, Δa*, and Δb* values were significantly lower when the thickness increased to 1.5 mm. VM7 demonstrated the same results with regard to the ΔL* and Δb* values, but Δa* did not show such a significant difference. With all the materials tested, it was observed that mean ΔE values were significantly higher in 1.0-mm-thick discs than in 1.5-mm discs. This indicates that the masking ability of the ceramic veneers increased as their thickness increased.

Among the three materials it was found that NRPA had significantly higher ΔL* values and lower

Table 4: *Multiple Comparisons of ΔL*, Δa*, Δb* and ΔE (Masking Ability) Among the Three Materials*

Color Coordinate	Material		Sig
ΔL*	**IPSe**	NRPA	.0001
		VM7	.243
	NRPA	IPSe	.0001
		VM7	.0001
	VM7	IPSe	.243
		NRPA	.0001
Δa*	**IPSe**	NRPA	.0001
		VM7	.0001
	NRPA	IPSe	.0001
		VM7	.0001
	VM7	IPSe	.0001
		NRPA	.0001
Δb*	**IPSe**	NRPA	.951
		VM7	.811
	NRPA	IPSe	.951
		VM7	.764
	VM7	IPSe	.811
		NRPA	.764
ΔE	**IPSe**	NRPA	.0001
		VM7	.227
	NRPA	IPSe	.0001
		VM7	.0001
	VM7	IPSe	.227
		NRPA	.0001

The mean difference is significant at the .05 level.

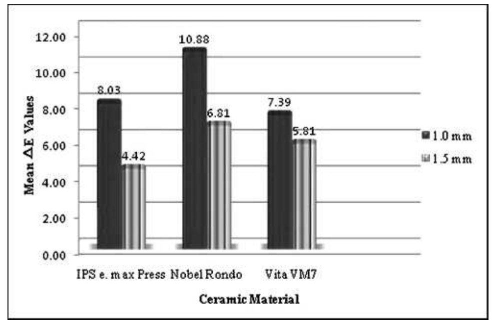

Figure 3. *Graph showing mean ΔE (masking ability) values for all ceramic specimens*

Δa* values (p=0.0001) when compared with IPSe and VM7. Also, VM7 demonstrated significantly higher Δa* values when compared with IPSe (p=0.0001), whereas ΔL* values were not significantly different between IPSe and VM7 (p=0.243). In addition, no significant differences were found in Δb* values among all three materials. It was observed that NRPA had significantly higher ΔE when compared with IPSe (p=0.0001) or VM7, whereas the ΔE of the latter two were not significantly different from one another (p=0.227; Table 4). In other words, the IPSe and VM7 are similar in their masking abilities, whereas NRPA had the lowest masking ability. Figure 3 shows the mean ΔE values of all ceramic specimens.

The results of the two-way ANOVA, presented in Table 5, showed a significant difference in the masking ability of the ceramics tested and between the different thicknesses of these materials; therefore, the null hypothesis was rejected. There was a significant material effect, thickness effect, and material-thickness interaction (p=0.0001).

When the thickness of the veneer was increased by 50% from 1 to 1.5 mm, VM7 exhibited a very small increase in its CR (4.7%) as compared with those

Table 5: *Two-way ANOVA Results for Comparisons of ΔE (Masking Ability) Values*

	Sum of Square	df	Mean Square	F	Sig
Material	120.976	2	60.488	42.22	.0001
Thickness	214.8	1	214.8	149.928	.0001
Material x Thickness	26.204	2	13.102	9.145	.0001

The mean difference is significant at the .05 level.

Table 6: *Percentages of Increase in Contrast Ratio Percentages and Decrease in ΔE Calues for all Ceramic Materials*

Ceramic Material	Percentages of Increase Contrast Ratio	Percentages of Reduction ΔE
IPSe	12.9	45
NRPA	13.9	37
VM7	4.7	21

exhibited by IPSe (12.9%) and NRPA (13.9%). On the other hand, ΔE values for IPSe showed the most significant reduction in ΔE values (45%), followed by NRPA (37%), whereas VM7 showed the least reduction (only 21%; Table 6).

Correlation

From the linear regression analysis it can be observed that there is a strong linear correlation between CR and masking ability (R=–0.80, p<0.0001, R^2=0.644; Figure 4). Furthermore, the Student *t*-test demonstrated that CR increased as the thickness of the discs increased to 1.5 mm for all three materials, which indicates that opacity of these ceramic materials increases as their thicknesses increase.

DISCUSSION

This *in vitro* study measured the masking ability and CRs of ceramic specimens prepared at different thicknesses. The hypothesis that there was no significant difference in the masking ability and CRs of the ceramics tested and between the different thicknesses of these materials was not supported by the results of this study. In addition, the hypothesis that there would be no correlation between the CR and the masking ability or the thickness of the three materials was also rejected.

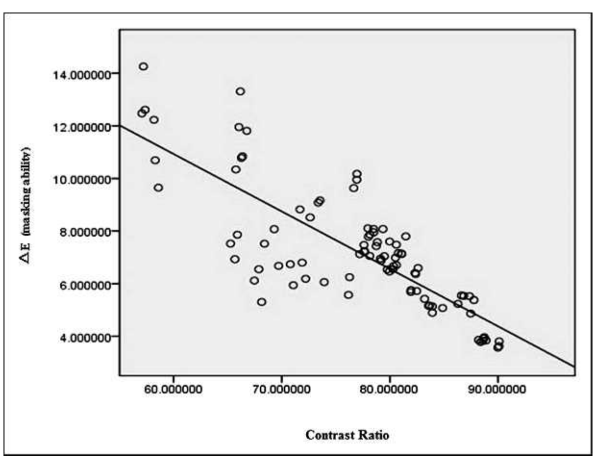

Figure 4. *Regression line for contrast ration (opacity) and ΔE (masking ability).*

The specimens used in this investigation had a thickness of 1.0 or 1.5 mm. It can be observed from the results that the L* a* b* values were affected by the thickness of the ceramic specimens. L* values decreased for all ceramic specimens as their thickness increased, indicating a decrease in brightness. As mentioned in the literature, this may be explained by the fact that more light is absorbed with thicker specimens and less is reflected; hence, lower L* values are recorded. Vichi and others[29] investigated the influence of ceramic and cement thickness on the masking ability of various types of opaque posts and concluded that the thickness of the ceramic was one of the dominant factors affecting the final color of the restoration. Another study demonstrated that the final shade of the porcelain can be influenced by small changes in the thickness of opaque and translucent porcelain layers.[31] The results of the present study are in agreement with two previous studies that have shown that as the ceramic thickness increased, L* values decreased for different types of all ceramic systems including leucite-reinforced ceramic (IPS Empress), a glass-infiltrated ceramic (In-Ceram Spinell), IPS e.max Press and zirconium oxide (DC-Zircon).[32,33]

All ceramic systems exhibited a decrease in a* and b* values with the increase in thickness. However, this decrease was not significant for VM7 with regard to a* values. These results suggest that the redness and yellowness of all specimens decreased as thickness of ceramic specimens increased. These results are not consistent with those of other studies where an increase in a* and b* values was observed with increased thickness of ceramic disks.[31–34] This diversity in results may be attributed to the difference in sample fabrication. The majority of the studies assembled the ceramic samples using a core and veneer combination, varying the thickness of each, whereas this study used only veneer ceramics in the fabrication of the samples.

For NRPA specimens the L* color values were found to be significantly higher and a* color values significantly lower than for IPSe and VM7. This suggests that NRPA is considerably lighter, even more translucent than the other two materials tested. The a* color values measured for VM7 specimens were greater than those obtained for IPSe and NRPA specimens. These findings indicate that VM7 ceramics have more redness, ie, greater warmth among the three materials evaluated in this study. All materials exhibited the same degree of yellowness because no significant difference was found in b* values. This comes as no surprise given that a shade of A2 was used for all specimens, and thus all ceramic samples will naturally exhibit the same degree of yellowness.

An increase in thickness has resulted in lower ΔE values for all ceramic specimens, which implies an increased masking ability with 1.5-mm-thick discs. These results are in agreement with those reached by Vichi and others[29] where ΔE values decreased as ceramic thickness increased from 1.0 to 1.5 mm. However, the same author has also observed that as ceramic thickness increased to 2.0 mm, no significant difference could be found with regard to the ΔE values. Similarly, Hilgert and others[35] found that increasing thickness of ceramic veneers from 0.4 to 0.7 and 1.0 mm resulted in lower ΔE values. Contrary to the previous studies Shokry and others[32] demonstrated that ΔE values increased as ceramic thickness increased. Ozturk and others[33] concluded that an increase in ceramic thickness, core (1.0 mm) and veneer (0.5, 1, or 1.5 mm), led to an increase in ΔE values for both types of all-ceramic specimens tested (IPS e.max Press and DC-Zirkon). This may be explained by the fact that the latter-mentioned study evaluated the effects of various ceramic thicknesses in combination with repeated firings on the color of ceramics. Repeated firings may have contributed to the significant color changes because several studies have suggested that certain metal oxides are not color stable during firing. Furthermore, color changes of surface colorants after firing have exhibited pigment breakdown at firing temperatures and therefore may affect the final color of ceramics.[36,37]

When the thickness of the veneer was increased by 50% from 1 to 1.5 mm, VM7 exhibited a very small increase in its ratio (4.7%) as compared with those exhibited by IPSe (12.9%) and NRPA (13.9%). This suggests that for the less translucent ceramics, the effect of thickness might not be significant. More translucent ceramics, however, allow more simulation of natural color by varying the thickness level and characterization. As for ΔE values, IPSe showed the most significant reduction in ΔE values (45%), followed by NRPA (37%), whereas VM7 showed the least reduction (only 21%). This indicates that the opacity of this material is innate to its composition and optical properties and less related to its thickness. With IPSe and NRPA, the effect of thickness is more pronounced, with IPSe showing a reduction in ΔE values almost equal to the percentage of increase in thickness. Overall, the results support the belief that feldspathic porcelains like VM7 are less translucent than the ultralow fusing ceramics.[23]

This study has shown that thickness of the veneering ceramic does affect the CR. For all the ceramics tested, the CR had a positive linear relationship with thickness. Antonson and Anusavice[23] evaluated the effect of thickness on the CR of veneering and core ceramics and concluded that CR was reliant on the type as well as the thickness of the material tested. Heffernan and others[24,30] described the effect of core ceramic thickness on its translucency as well as the influence of core plus ceramic veneer thickness on the overall translucency of the specimens and were able to identify a significant range of translucency. The present study confirms that the thickness of ceramics may influence the opacity. In addition, a positive linear relationship between opacity and ability of veneers to mask backgrounds was confirmed, which is in agreement with the results found in previous studies.[25,38]

ΔE values for NRPA specimens were considerably higher than for IPSe and VM7 specimens. Moreover, CR percentages calculated for NRPA were lower than those obtained for IPSe and VM7. These results indicate that masking ability and CRs of IPSe and VM7 were significantly better than those for NRPA. The optical properties of the different constituents in core and veneer materials and the thickness of each material are considered to be the main factors that influence the CR and masking ability of any ceramic system.[25] When a high percentage of alumina is incorporated in the composition of a ceramic, it is believed that it intercepts the incident light more efficiently and subsequently increases the ceramics opacity and masking ability. IPSe is approximately 70% lithium disilicate glass ceramic, with its main component being silicon dioxide (SiO_2). According to the manufacturer additional components of lithium oxide (Li_2O), potassium oxide (K_2O), magnesium oxide (MgO), zinc dioxide (ZnO_2), aluminum trioxide (Al_2O_3), phosphorus pentoxide (P_2O_5) and other oxides are also present within its composition. Due to the use of new technologies and optimized processing parameters, the formation of defects in the bulk of the ingot is avoided. Lithium disilicate, the main crystal phase, consists of needle-like crystals measuring 3 to 6 μm in length. VM7 is fabricated from glass frits melted in metal oxides, and it is characterized by its enamel-like light refraction and reflection properties. Furthermore, the use of additional fluorescent and opalescent porcelains enables highly individual restorations with a high standard of esthetics to be achieved with these ceramics. NRPA was developed to enable new applications of individual inlays, onlays, and veneers without a supporting framework.

In theory, the masking ability of a porcelain veneer is considered to be perfect when it will have no color change over white and black backgrounds, ie, $\Delta E = 0$. If that is the case, the veneer is "color stable" over white and black backgrounds. There is a controversy in the literature about the ΔE values that are acceptable clinically. Several studies found that ΔE values as low as one unit are visually detectable.[39,40] On the other hand, Ruyter and others[41] reported a threshold for visually acceptable color change to be up to 3.3 units. Another study reported a visual match between a resin composite veneer and a tooth when the mean ΔE was 3.7 units.[42] Chu and others[38] considered $\Delta E \leq 5$ to be the representative value of acceptable color difference for veneers with the corresponding CR percentage to be at 0.91, above which the restoration is capable of masking the background color changes from white to black. The author stated that estimating a threshold CR percentage is helpful in predicting whether a porcelain veneer or crown will be affected by the underlying tooth color. In the present study none of the veneers had a ΔE below 5 or a CR over 0.91. Therefore, it is acceptable to say that the porcelain veneers with 1.0- or 1.5-mm thickness were not completely able to mask the underlying black background, although their masking ability improved with increased thickness. Thus, if the clinical situation requires color masking, thicker, more opaque materials should be used.

It is the responsibility of the clinician to fully understand the limitations of veneers in masking severe discolorations, taking into account that each ceramic system is unique in its optical properties. This will ultimately affect the final esthetics of the restoration; therefore, the type of ceramic needs to be chosen according to each clinical situation.

Finally, further studies are needed to evaluate the clinical implications of these findings. In some clinical situations varying degrees of dark stains need to be masked. Therefore, the interaction between the background color and the thickness of the veneer needs to be examined. A range of different background colors mimicking the stains a clinician may encounter should be used along with different thicknesses of the veneers. Furthermore, different shades of ceramic veneers, other than A2, and luting cements used in the clinic may also be used to accurately imitate the clinical situation. In addition, the effect of daylight and incandescent and fluorescent lights must be considered, because it has been shown that they do influence the resultant color of the ceramic restorations.

CONCLUSIONS

Within the limitations of this study the following conclusions can be drawn:

1. CRs and masking abilities are affected by the types and thickness of the ceramics.
2. NRPA demonstrated the least masking ability among the three ceramics tested. IPSe and VM7 were similar in their masking abilities, but IPSe exhibited higher CR percentages than did VM7.
3. All the materials tested in this study were not capable of completely masking the underlying black background, although the masking ability improved when the thickness was increased from 1.0 to 1.5 mm.
4. There is a strong linear relationship between masking ability and CR.
5. The clinician needs to understand the limitations of the ceramic veneers in masking severely stained teeth. In addition, each ceramic system has distinctive optical properties that may influence the final appearance of the restoration. Therefore, the type of ceramic should be chosen according to each clinical situation.

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