Threshold Contrast Ratio and Masking Ability of Porcelain Veneers with High-Density Alumina Cores

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Purpose: The purposes of this study were to: *(1)* investigate the correlation between the color difference of bilayer porcelain veneers over white and black backgrounds (ΔE1) and their opacity (contrast ratios); *(2)* determine whether there is a recommendable threshold contrast ratio above which the color difference is clinically acceptable (when ΔE ≤ 5); and *(3)* compare the ability of porcelain veneers to mask a color change from white to black backgrounds (ΔE1) and their ability to mask a color change from white to clinically discolored teeth (ΔE2). **Materials and Methods:** Forty-four maxillary anterior teeth of eight patients with severe tetracycline discoloration were prepared for bilayer porcelain veneers in shade A2 porcelain. The cores were 0.25 mm thick. The color (CIE L*a*b*) and reflectance (Y) of the midbuccal region of each veneer were measured over white and black backgrounds using a colorimeter under artificial daylight. The veneers were bonded to discolored teeth, and their color was measured after 1 week. **Results:** The mean color difference ΔE1 was 10.6 (SD 2.6). The mean contrast ratio was 0.75 (SD 0.1). There was a close and statistically significant correlation between ΔE1 and contrast ratio. The determined threshold contrast ratio was 0.91. The mean color difference ΔE2 was 11.6 (SD 5.5). A paired *t* test showed no difference between ΔE1 and ΔE2. **Conclusion:** There was a significant correlation between the masking ability of veneers (ΔE1) and their opacity (contrast ratio). There was no significant difference in the ability of the porcelain veneers in masking a color change from white to black backgrounds compared to their ability to mask the color change from white to the discolored teeth. *Int J Prosthodont 2004;17:24–28.*

Clinicians claim that porcelain of high opacity should be used to reduce the perceived color difference of porcelain veneers after their bonding to discolored tooth substance.[1] Manufacturers have introduced porcelain systems with increased opacity and claim superior color stability over different backgrounds. A study reported that among the various all-ceramic systems for the construction of porcelain veneers, high-density alumina core (Procera AllCeram, Nobel Biocare) has the highest opacity.[2] For the core materials used in the construction of porcelain veneers, a report showed that a 0.5-mm-thick high-density alumina core (Procera) is as opaque as a 0.8-mm-thick layer of lithium disilicate ceramic (Empress 2, Ivoclar Vivadent).[3]

Although the opacity (contrast ratio) of porcelain restorations has been determined,[4] no study has investigated the correlation between the opacity of porcelain and the color difference of porcelain veneers over different backgrounds. The purposes of the present study were to: *(1)* investigate the correlation between contrast ratio (opacity) and color difference of bilayer veneers with high-density alumina cores over white and black backgrounds (ΔE1); *(2)* determine

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Fig 1 Veneers placed over a white background.

Fig 2 Veneers placed over a black background.

the threshold contrast ratio above which the veneers show an "acceptable" color difference; and *(3)* determine if there is a difference in the ability of porcelain veneers to mask a color change from white to black backgrounds (ΔE1) versus their ability to mask a color change from white to clinically discolored teeth. The null hypotheses of the study were that there would be: *(1)* no correlation between the color difference of the veneers measured over white and black backgrounds and their contrast ratio; and *(2)* no difference in the ability of the veneers to mask the color difference between white and black backgrounds and their ability to mask the color difference between white and the color of discolored teeth.

Materials and Methods

Forty-four porcelain veneers for eight patients with severely tetracycline-stained teeth (14 maxillary central incisors, 12 lateral incisors, and 18 canines) were constructed for the study. The mean L*, a*, and b* values of the midbuccal region of the discolored teeth before treatment were 48.5 (standard deviation [SD] 7.6), 5.1 (SD 1.2), and 13.4 (SD 3.2), respectively. The labial reduction was about 0.5 mm in the cervical region, and reduction for the remaining preparation was about 0.7 to 1.0 mm. The labial reduction was extended to about half of the proximal area, and care was taken not to remove stable proximal contacts. Incisal edges were reduced by about 1.0 mm.

All the working dies were scanned using the manufacturer's computer-aided design (CAD) program (Nobel Biocare) for the construction of 0.25-mm-thick high-density alumina cores. The cores had a mean thickness of 0.25 mm (SD 0.03). The cores returned from the manufacturer were then veneered with a feldspathic porcelain (AllCeram, DuCera; shade A2 Vita Lumin shade guide) to the final contour by a designated technician. All veneers were built up within three firing cycles at 900 to 930°C with a calibrated furnace (Vita Vacumat 300). The mean total thickness of the midbuccal region of finished veneers was 1.04 mm (SD 0.27).

All veneers were cleaned in an ultrasonic water bath for 5 minutes and dried before placement on a silicone fixture for colorimetric measurements. A colorimeter (model CS-100, Minolta) with a 1-degree measuring angle and a close-up lens was used. The colorimeter was calibrated with a standard glossy white calibration plate (CS-A20, Minolta; Y = 95.7, x = 0.3170, y = 0.3347) under artificial lighting using a circular fluorescent lamp of 20.32 cm diameter and a daylight color temperature of 6,500 K. A color temperature meter (Profi-Color, Gossen) was used to monitor performance of the fluorescent lamp throughout the experiment. The color (as CIE L*a*b*) and reflectance (as Y) of a circular area 1.3 mm in diameter at the midbuccal region of the veneers were measured over white and black tiles (Minolta) (Figs 1 and 2). Color was measured again 1 week after veneers were bonded to the discolored teeth with a shade A2 resin cement (Choice PVS, Bisco) (Figs 3 and 4). Colorimetric data in CIE L*a*b* and Yxy values were recorded and printed out by a data processor (model DP-101, Minolta) connected to the colorimeter. In CIE L*a*b* colorimetry, the color of an object is defined in a three-dimensional color space expressed in three coordinates: L* = brightness (white-black); a* = redness to greenness; and b* = yellowness to blueness. The Y value in Yxy color space represents reflectance, where x = value of hue and y = value of chroma.[4,5] Each printed reading was the mean of three repeated measurements.

The color difference (ΔE1) of veneers over the white and black backgrounds, and the color difference (ΔE2) of veneers over the white background and after bonding to discolored teeth were determined. ΔE1 represents the most extreme color difference of a veneer because of a change in background color, eg, from white to black background. ΔE2 is the color difference of a veneer over a white background and after its bonding to discolored tooth substances. Both ΔE1 and ΔE2 reflect the masking ability of the veneers.

Fig 3 Generalized tetracycline staining of teeth.

Fig 4 Bonded veneers.

The color difference of the veneers (ΔE) over different backgrounds was calculated using the following equation:

$$[(L^*_1 - L^*_0)^2 + (a^*_1 - a^*_0)^2 + (b^*_1 - b^*_0)^2]^{1/2}$$

where L^*_1, a^*_1, and b^*_1 = color coordinates of the veneers over a white background; and L^*_0, a^*_0, b^*_0 = color coordinates of the veneers over the black background or discolored teeth. The contrast ratio (Yb/Yw) is defined as the ratio of reflectance from the test material when it is placed on the black background (Yb) to the reflectance from the same material when it is placed over a white background (Yw).

The reproducibility of measurements was assessed by computing the standard error (SE) of 30 repeated measurements of Y and L*a*b* values of the midbuccal region of a central incisor of one subject. The means of the measurements of Y, L*, a*, and b* were 41.3 (SE 0.32), 70.4 (SE 0.22), 2.3 (SE 0.04), and 16.9 (SE 0.07), respectively. The magnitude of the SEs was considered insignificant for the purpose of the experiment. Prism 3.0 statistics software (GraphPad Software) was used to determine the correlation (Pearson correlation coefficient) between contrast ratio and color difference of the veneers over white and black backgrounds ($\Delta E1$) ($P = .05$). The threshold contrast ratio above which the color difference of the veneers as measured over white and black backgrounds was determined by correlating the value of contrast ratio on the $\Delta E1$/contrast ratio plot at $\Delta E = 5$. The value of $\Delta E = 5$ was chosen for the purpose of this experiment to be the threshold value for clinical acceptability. Paired *t* test analysis was performed to compare the color difference values $\Delta E1$ and $\Delta E2$ ($P = .05$).

Results

The mean contrast ratio measured was 0.75 (SD 0.07), and the mean $\Delta E1$ was 10.6 (SD 2.6). None of the veneers had a $\Delta E1$ below 5. The correlation between contrast ratio and $\Delta E1$ was statistically significant ($r = -.94$, $P < .001$, $R^2 = .88$). When a ΔE of $\leqslant 5$ was chosen as the value representing "acceptable" color difference for veneers, the corresponding contrast ratio was 0.91 (Fig 5). The mean $\Delta E2$ was 11.6 (SD 5.5). Only three veneers had a $\Delta E2$ below 5. Paired *t* test analysis comparing $\Delta E1$ and $\Delta E2$ showed no statistically significant difference ($P > .05$).

Discussion

A study of porcelain veneers for patients is more informative in ascertaining the masking ability of veneers than veneers of standard dimensions. Although the variations in core and veneer porcelain thickness and surface finish were unavoidable despite attempts to control them in this experiment, the effects of these small variations on the results can be regarded as insignificant.

In principle, if the masking ability of a porcelain veneer is perfect, it will have no color difference over white and black backgrounds, ie, $\Delta E1 = 0$. In other words, the veneer is "color stable" over white and black backgrounds. With different values of ΔE reported for the evaluation of color stability of dental materials, it was found that a ΔE value as low as 1 unit is visually detectable/perceptible.[6,7] However, the threshold for visually acceptable color difference reported by Ruyter et al[8] is up to 3.3 units. A clinical study reported a visual match between a resin composite veneer and a tooth when the mean ΔE was 3.7 (SD 2.4).[9]

Because of the limited thickness of a porcelain veneer and the severity of tetracycline staining, the achievement of a color difference of 3.7 would probably be unrealistic. Porcelain veneers are usually placed over all discolored anterior teeth and do not have to match the color of natural teeth. In one study, veneers with a color difference of 6.8 (SD 2.7) were regarded as a mismatch.[9] In the present study, the mean of 3.7 and 6.8 to the nearest integer, ie, $\Delta E = 5$,

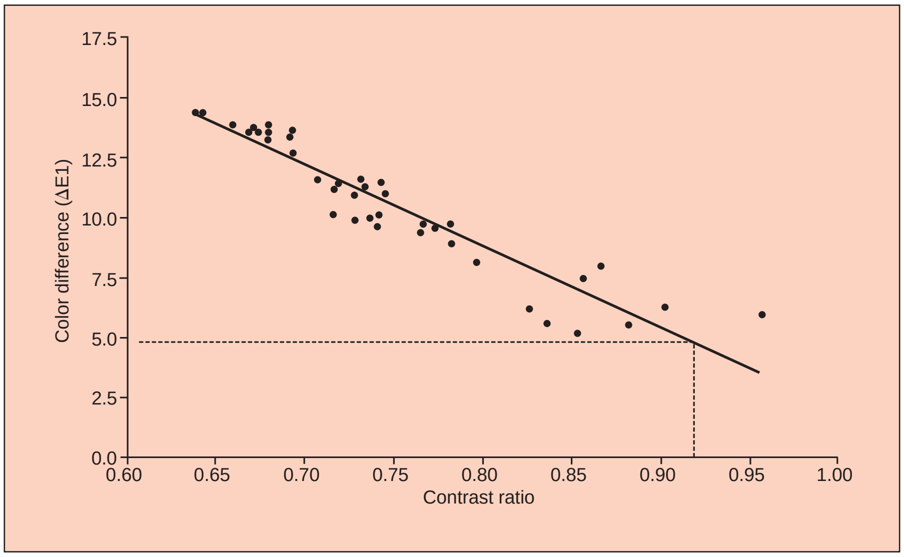

Fig 5 Regression line for contrast ratio and color difference.

was therefore regarded as the threshold value indicating acceptable masking ability.

The ΔE1 values in our study represent the most extreme color difference perceivable of a veneer, ie, a change from a white to a black background, and all of the veneers had a ΔE1 greater than 5. In practical terms, the veneers were not able to totally "mask" the underlying black background.

Although all the veneers were constructed by one technician, the contrast ratio values of the bilayer veneers in the present study ranged from 0.65 to 0.96. Unlike the disk-form specimens—uniform in color and thickness—used for an in vitro study,[10] the veneers constructed in this clinical study had a range of contrast ratio values that could be explained by the variation in dentin and enamel porcelain layering.[11] Our study confirmed the relationship between the opacity and ability of the veneers to mask a background color change from white to black. Color masking ability can be explained by the opacity of the veneer, which is derived from the added opaque colorants that effectively "intercept" the incident light by specular and diffuse reflection.[12]

The contrast ratio value of 0.91 corresponding to ΔE = 5 was regarded as the threshold contrast ratio in this study. The threshold contrast ratio value is useful in predicting whether a porcelain veneer or all-porcelain crown will be affected by the underlying tooth color, presuming the worst-case scenario of the most severe discoloration, ie, black. The concept of a threshold value can also be used for further research on the masking ability of other porcelain restorations.

The ability of the veneer to mask the color difference between a white background and after bonding to discolored teeth was measured as ΔE2 in this study. The SD of ΔE2 (5.5) was higher than that of ΔE1 (2.6). The difference can be explained by the varying degrees of discoloration of the teeth for ΔE2, compared with a standardized black background for ΔE1. However, a paired comparison of ΔE1 and ΔE2 did not show significant differences. The ability of the veneers to mask a color change from white to black (ΔE1) was not significantly different from their ability to mask color difference between a white background and a group of discolored teeth (ΔE2). The use of ΔE1 is a more stringent measurement of masking ability of veneers than ΔE2 because of its assessment of the most demanding masking ability of a color change, from white to black. Its advantage over the use of ΔE2 could be the use of a standard black background. None of the veneers showed a color difference (ΔE1) of below 5. Only 3 of 44 clinically bonded veneers had a ΔE value of below 5, which meant that the majority of the veneers could not effectively mask the severely discolored teeth in this study.

The findings of our study indicate that the masking ability of porcelain veneers with 0.25-mm-thick core and 0.75-mm-thick veneering porcelain was not sufficient for the majority of the selected group of discolored teeth. If the threshold contrast ratio is desired without further tooth reduction or overcontouring the restoration, then increasing the core thickness at the expense of the thickness of veneering porcelain will be necessary. However, highly opaque restorations may appear "lifeless," although they have good masking ability. On the other hand, to increase the thickness of the veneer will require reduction of more tooth substance, which increases the risk of pulpal trauma.

A clinician has to take into account the severity of the tooth discoloration and understand the limitation of porcelain veneers in masking severe discoloration.

Conclusion

There was a close and significant correlation between the masking ability of veneers ($\Delta E1$) and their opacity (contrast ratio). A threshold contrast ratio of 0.91 was determined to be the value above which the restoration can mask the background color change from white to black. The veneers' ability to mask the background color change from white to black was not significantly different from their ability to mask the color changes from a white background to a group of severely discolored teeth.

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Literature Abstract

3-D finite element analysis of all-ceramic posterior crowns.

This article examined the distribution of stresses on single- and double-layer crowns using 3-D finite element analysis. The models simulated single-layer crowns fabricated of Dicor and Empress and double-layer crowns fabricated of In-Ceram and Empress 2 high-strength core ceramics and a veneering tooth-colored porcelain. The following loads were applied: vertical, to simulate maximum bite force totaling 600 N; and inclined load, to simulate masticatory force applied at 0, 45, and 90 degrees on the outer incline of the buccal cusps totaling 225 N. For loads simulating maximum bite force, the single-layer crowns exhibited a maximum tensile stress of 18.2 to 18.3 MPa, concentrated around the loading points along the crown surface. No concentration of tensile stresses was observed inside the crown. Double-layer crowns had a tensile stress maximum range of 18.1 MPa (Empress 2) to 9.4 MPa (In-Ceram) along the surface of the crowns. They also exhibited internal stresses ranging from 11.7 to 17.4 MPa on the inner core. For loads simulating masticatory forces, single-layer crowns had a concentration of tensile stresses ranging from 10.8 to 10.9 MPa, which decreased as the loading direction was inclined. Stresses again increased when loads were applied horizontally, and even reached up to 27 MPa for In-Ceram. Although it cannot be concluded from this study that double-layer ceramic crowns are less likely to fracture than single-layer crowns, it can be surmised that they do have applications in higher stress-bearing areas in the mouth.

Imanishi A, Nakamura T, Ohyama T, Nakamura T. *J Oral Rehabil* 2003;30:818–822. **References:** 22. **Reprints:** Dr Takashi Nakamura, Division of Oromaxillofacial Regeneration, Course for Integrated Oral Sciences and Stomatology, Osaka University Graduate School of Dentistry, 1-8 Yamadaoka, Suitaa, Osaka 565-0871, Japan. e-mail: tnakamura@dent.osaka-u.ac.jp—*Josephine Esquivel-Upshaw, San Antonio, Texas*