Color and translucency of zirconia infrastructures and porcelain-layered systems

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With technological advances and the increase in esthetic requirements, ceramic alternatives to metal substructures have been developed. Ceramic restorations have excellent esthetic properties, chemical stability, and biocompatibility.[1] However, ceramic dental restorations had been limited to the anterior region because of the brittle character of dental ceramics and its low resistance to fracture in bending.[2] The development of higher strength dental ceramic systems has been followed by their use in the posterior regions. Zirconia ceramics with good mechanical properties, biocompatibility, and resistance against tensile forces may now be used in the posterior regions and for long-span fixed partial dentures. Although satisfying esthetic results can be accomplished with ceramic systems, the use of a fracture-resistant core material is necessary to withstand clinical functional and parafunctional forces.

ABSTRACT

Statement of problem. A good color match combined with a proper translucency match results in excellent esthetics for a metal-free restoration, yet basic color and translucency comparisons between available zirconia systems are not well described.

Purpose. The purpose of this in vitro study was to compare the color and translucency of commercially available zirconia materials.

Material and methods. Eight specimen disks were formed in each of the single-layer (0.5-mm thick) groups and double-layer (0.5-mm zirconia with 1.0-mm porcelain) groups for each of 5 zirconia-based substructure systems. Colors on black, gray, and white backings were used to obtain CIEDE2000 color differences between the zirconia systems in the layering groups and to obtain relative translucency parameter (RTP) values. Color differences were compared with perceptibility and acceptability thresholds, and comparisons in RTP were made using analyses of variance and the Bonferroni corrected Student t tests (α=.05).

Results. The Shrout-Fleiss random set reliability for the duplicate L* determinations was 0.9992, 0.9756 for a*, and 0.9959 for b*. Although some mean color differences were below or at the perceptibility threshold, most differences were at or above the acceptability threshold. For the single-layer configuration, 1 material system had higher RTP values than every other material ($P<.001$), and another material had lower RTP values than every other material ($P<.001$).

Conclusions. The results of this study present significant differences in both color and translucency among 5 ceramic substrate systems when studied in single layers. Perceivable and often unacceptable differences in color were also found among these materials when layered with porcelain. It is concluded that the esthetics of restorations which use a ceramic substrate is notably affected by the ceramic system used. (J Prosthet Dent 2019;121:510-6)

Although initial color may be less important to the long-term clinical success of dental restorations, appearance plays an important role in the success of the restoration for the patient, and so color has become an

important determinant for patient acceptance.[3] Color standardization in terms of comparison and color matching in a systematic color-selection process have been established and assessed for various colorimetic devices.[4]

Because of their opaque appearance, the originally introduced zirconia ceramics have been commonly veneered with feldspathic ceramic to produce a more esthetically pleasing appearance. Nevertheless, the opacity of the core material affects overall translucency and the esthetics of the restoration. Heffernan et al[5] reported that zirconia ceramic had opacity similar to that of a dental alloy at the thickness of interest for clinical use. When compared with other ceramic systems, the opacity of zirconia was greater than that of any of the alumina spinel and feldspathic core materials studied. However, Baldissara et al[6] claimed zirconia to be translucent. There are known variations in the exact composition and structure of dental zirconia materials.[7,8] Variation in material thickness is also known to affect the color and translucency of layered esthetic dental materials.[5,9–11] Substrate materials should have the strength, color, and translucency to obtain durable esthetic results and should be compatible with any veneering material to maintain integrity.

A commonly used color order system is the 1976 CIELab color space.[12] Within dentistry, this color space has been used to evaluate the colors of and color differences among various natural and restorative esthetic materials.[13] Perceptibility and acceptability limits have been determined for levels of color differences using both the CIELab and the CIEDE2000 color difference formulae.[14] Although matching according to visual color judgment is still performed in dentistry, this process involves both the perception of color difference and the personal interpolation of color differences. Issues regarding perceptibility and acceptability thresholds of color differences in artificial dental settings[15,16] have resulted in a variety of threshold estimates.[14,17,18] Nevertheless, such thresholds provide useful interpretation of the magnitude of in vitro–determined color differences.

Translucency is the state between complete opacity and transparency[19,20] and may be characterized by the translucency parameter (TP), which is defined as the color difference of a material of a given thickness in optical contact with ideal white and black backgrounds[21] and corresponds directly with common visual assessment.[22] A TP value of zero is indicative of a completely opaque material, and the greater the TP value, the higher the translucency of the material, with the maximum TP value being the color difference between the ideal backings.[23] Recently, the use of the CIEDE2000 color difference formula has been suggested for calculating TP.[24] Furthermore, the relative translucency parameter (RTP), relative to the colors of the actual backings used in the color difference determinations, has been suggested for use with materials that are not completely uniform throughout the thickness of the material.[25] A good color match combined with an appropriate translucency match usually results in outstanding esthetics of the restoration.[20,26,27]

Core translucency is a main factor in selecting a material that will provide an esthetic restoration.[28,29] Translucency is closely related to light scattering, and the scattering of particles larger than the wavelength of visible light depends on the relative refractive indices of the matrix and particle.[30,31] Today's ceramic systems contain opaque core materials that provide mechanical resistance of the restoration and require veneering.[32] Although opaque materials hide the background, more translucent materials are affected by the background color because this is reflected through the translucent material.[33] As an adjunct to a previous study,[5] Heffernan et al[34] reported a decrease in contrast ratio or an increase in translucency of some glazed ceramics and linked this decrease in opacity to decreased scattering in the glaze.

To quantitatively describe the color and translucency of various commercial zirconia materials for this purpose, the in vitro color and translucency properties of 5 different zirconia-based infrastructure systems were compared in a single layer and when layered with porcelain. The null hypotheses of the study were that no differences would be found in the color and translucency properties of the ceramic substrate systems studied when considered alone or layered with porcelain.

MATERIAL AND METHODS

Five different zirconia-based infrastructure systems as described in Table 1 were evaluated. Disks within each zirconia system were divided into 2 groups, with each disk of the single-layer groups left as a single layer of zirconia of 14 mm in diameter and 0.5 mm in thickness. Specimens were prepared following the manufacturer's instructions. Disks within double-layer groups of each system were formed by the zirconia core being covered with veneering feldspathic porcelain with an added porcelain thickness of 1.0 mm. Eight specimens were formed in each of the single-layer groups and double-layer groups.

Table 1. Zirconia materials studied

Zirconia Core Material	Material Code	Manufacturer
Rainbow	R	Dentium
Rainbow Translucent	T	Dentium
ICE Zirkon	Z	Zirkonzahn GmbH
Prettau	P	Zirkonzahn GmbH
Lava	L	3M ESPE

For the double-layer specimens, wax patterns, 14 mm in diameter and 1.5 mm in thickness, were made using inlay wax placed in a polyvinyl siloxane putty mold. A conventional veneering ceramic (IPS e.max Ceram; Ivoclar Vivadent AG) was applied on the cores to a thickness of 1 mm. Veneering porcelain slurry was condensed and hand vibrated; excess moisture was removed with absorbent paper tissue to minimize porosity. The condensed specimens were fired in a vacuum furnace (Programat P300; Ivoclar Vivadent AG). Dentin firing program (program no.: 33) was used with a temperature increase rate of 50 °C/ minute, holding temperature of 750 °C, and holding time of 1 minute. No glazing cycle was used. The porcelain surface was polished with abrasive paper disks of 320, 600, 1200, and 2400 grit to adjust the final thickness. Specimen thickness was measured with digital calipers. Specimens were ultrasonically cleaned in distilled water for 10 minutes. Each of the specimens was then inspected under a microscope to ensure that no surface porosity was present. The uniformity of the thicknesses was evaluated by a 2-way analysis of variance, where the 2 factors were the material and layering (α=.05).

For each single- and double-layered specimen, the reflectance spectrum was determined on each of 3 backings, black, white, and gray, according to the method described previously.[35,36] Briefly, a spectroradiometer (PR 705; Photo Research Inc) and the light-emitting end of the fiber optic light cable were fixed on an optical table. The fiber optic light cable was connected to the xenon-arc lamp (Thermo Oriel Lamp Housing 66 904 and Power Supply 69 911; Newport Corp). The spectroradiometer and the optic light cable provided an optical configuration of 0-degree observation and 45-degree illumination to the object. Spectral radiance was obtained from 380 nm to 780 nm in 2-nm increments (SpectraWin 2.0; Photo Research Inc) and subsequently converted to spectral reflectance using a white reflectance standard (Spectralon Diffuse Reflectance Standard S3796A; Labsphere Inc). To maintain accuracy of the reflectance results, measurements of a white standard were made before and after each specimen.[13] The spectroradiometer was positioned 8 cm from the measured object, yielding a measurement diameter of 1.1 mm. The accuracy and reliability of obtained colors from this system have been previously evaluated.[35] Each single-layer and double-layer specimen was then measured in optical contact with each of black, gray, and white backings.

Saturated sucrose solution with an index of refraction of approximately 1.5 was placed as the optical contact between the specimen and the backing. Each reflectance spectrum was converted to CIELab values for the CIE D65 illumination and the CIE 2-degree observer.[12]

Duplicate reflectance and color determinations were obtained for randomly selected single-layer specimens with all 3 backings to confirm the reliability of the reflectance and color parameter determinations using the intraclass correlation coefficient.[37] This randomization was obtained by ranking the single-layer specimens based on spreadsheet-generated random numbers and selecting 8 specimens with the highest rankings. Then, every duplicate reflectance determination was averaged for subsequent analysis, with color determinations based on the respective mean reflectance spectrum.

The Commission Internationale de l'Eclairage [International Commission on Illumination] (CIE)color parameters were subjected to a repeated measures 4-way analysis of variance (α=.05) using Type III tests of statistical significance and maximum likelihood estimation of variances[38,39] and Satterthwaite degrees of freedom[40,41] methods that allow for nonnormality of the data and correct for nonhomogeneity of variances. This analysis involved the 4 main effects of the material, layering, backing, and the CIE color direction, where both the backing and the CIE color direction were within-subject factors. This analysis considered all interactions.

Color difference determinations (CIEDE2000) were made for the colors determined on the gray backing (L*=70.2, a*=−0.7, and b*=1.4) following the base technique for color determination[42] but using color differences between materials within each layering. RTP was determined as the CIEDE2000 color difference between the colors obtained for each specimen on the black (L*=11.0, a*=1.4, and b*=−0.6) and white (L*=93.6, a*=−0.1, and b*=1.4) backings. Mean color differences on the gray backing were compared with perceptibility and acceptability thresholds[14] to provide a measure of magnitude. The RTP data were subjected to an analysis of variance involving the 2 main effects of material and layering and their interaction (α=.05). If a statistically significant interaction was found, pairwise comparisons between materials within each layering configuration and between the layering configurations within each material were tested with the Bonferroni corrected Student t tests.

RESULTS

The analysis of specimen thickness found a statistically significant difference [$F_{(1,70)}$=195 679, P<.001] between the thickness values for the 2 layering configurations as expected, but no statistically significant difference involving the materials was found either as a main effect [$F_{(4,70)}$=0.60, P=.660] or as an interaction [$F_{(4,70)}$=0.88,
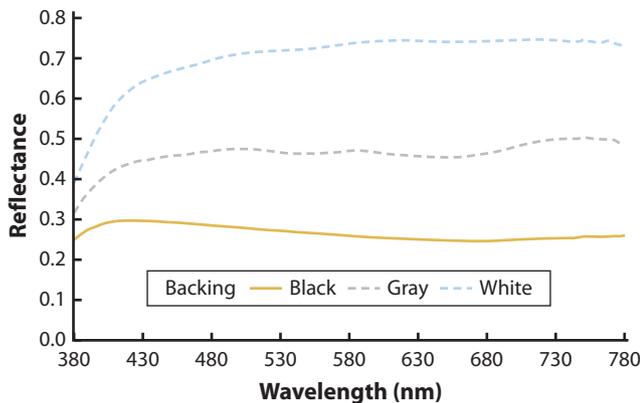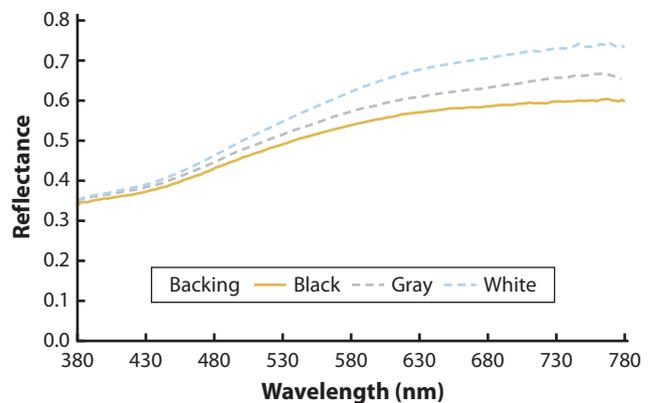
Figure 1. Average reflectance spectra for single layer of material P over 3 backings.
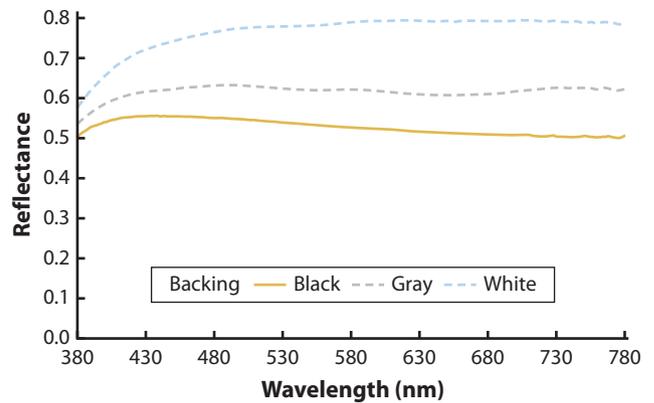
Figure 2. Average reflectance spectra for single layer of material T over 3 backings.
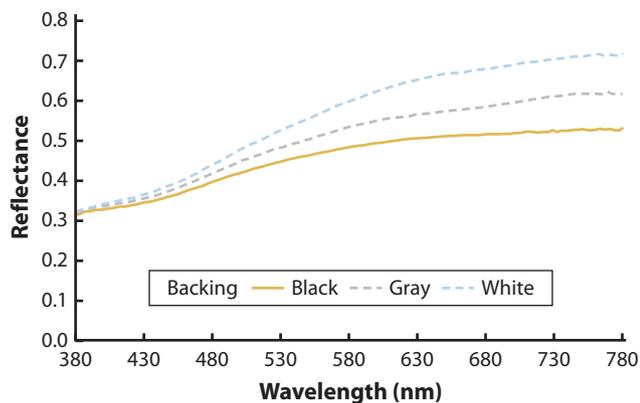
Figure 3. Average reflectance spectra for porcelain layer over material P and over 3 backings.

Figure 4. Average reflectance spectra for porcelain layer over material T and over 3 backings.

P=.480] with the layering. The mean ±standard deviation thickness for all single-layer specimens was 0.51 ±0.004 mm, and for all double-layer specimens, it was 1.51 ±0.014 mm.

To assess reliability, 4824 reflectance determinations were duplicated, as these determinations were duplicated for each of 201 wavelengths for each of 8 specimens on each of 3 backings. The Shrout-Fleiss random set reliability for the duplicate reflectance determinations was 0.9988. The CIELab color parameters were determined from each of the 48 spectra described previously, as 24 color determinations were duplicated for each of these 8 specimens on each of 3 backings. The Shrout-Fleiss random set reliability was 0.9992 for the duplicate L^* determinations, was 0.9756 for a^*, and was 0.9959 for b^*.

The determined reflectance spectra were averaged for the specimens within each material and layering configuration for these examples. Figures 1-4 display the average reflectance spectra of materials with high (material P) and low (material T) translucency values for the single and double layers.

The summary of analysis of the color parameters is presented in Table 2 and indicates that the 4-way interaction among material, layering, backing, and the color direction was statistically significant (P<.001) and justifies rejecting the null hypothesis regarding no differences in color. Resolving this hypothesis completely for every pairwise comparison of the materials studied for each layering configuration on the gray backing would be beyond the objectives of this study as the real issue becomes the total color differences among materials. Therefore, only the resultant color differences between material pairs for each layering configuration on the gray backing are presented.

The means and 95% confidence levels of the means of the CIEDE2000 color differences are shown in Figure 5 for the pairs of materials studied for each layering configuration. Also shown are perceptibility and acceptability limits.[14]

The summary of analysis of RTP is provided in Table 3 and indicates that the 2-way interaction between material and layering was statistically significant (P<.001) and justifies rejecting the null hypothesis regarding no differences in translucency. The means and 95% confidence

Table 2. Summary of Type III tests of significance for CIE color parameters

	Effect	df	SS	MS	F-Ratio	P
Between Subjects	Material	4	340.69	85.17	33.11	<.001
	Layers	1	4525.34	4525.34	1759.06	<.001
	Material × layers	4	128.27	32.07	12.46	<.001
	Error	70	180.08	2.57		
Within Subject	CIE direction	2	5540.56	2770.28	3199.26	<.001
	CIE direction × material	8	211.19	26.40	30.49	<.001
	CIE direction × layers	2	980.25	490.13	566.02	<.001
	CIE direction × material × layers	8	81.37	10.17	11.75	<.001
	Error (CIE direction)	140	121.23	0.87		
	Backing	2	877 888.36	438 944.18	92 621.82	<.001
	Backing × material	8	681.11	85.14	17.97	<.001
	Backing × layers	2	10 473.06	5236.53	1104.96	<.001
	Backing × material × layers	8	580.03	72.50	15.30	<.001
	Error (backing)	140	663.47	4.74		
	CIE direction × backing	4	2930.72	732.68	1593.89	<.001
	CIE direction × backing × material	16	175.73	10.98	23.89	<.001
	CIE direction × backing × layers	4	1782.71	445.68	969.54	<.001
	CIE direction backing × material × layers	16	143.49	8.97	19.51	<.001
	Error (CIE direction × backing)	280	128.71	0.46		

CIE, International Commission on Illumination; MS, mean square; SS, sum of squares.
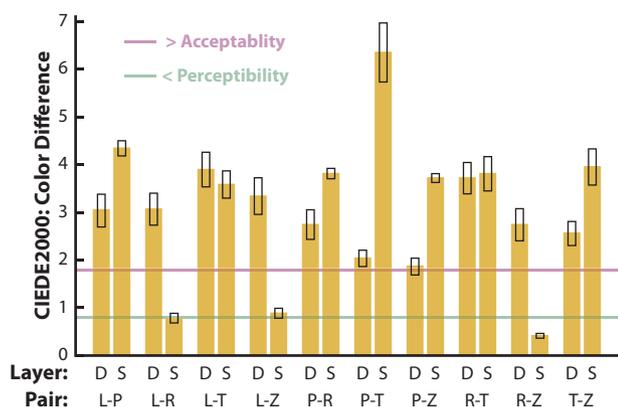
Figure 5. Means and 95% confidence limits of color differences between every pair of materials studied by layering configuration. D, double Layers; S, single Layer. Perceptibility and acceptability limits[14] also indicated.

Table 3. Summary of Type III tests of significance for relative translucency parameter

Effect	df	SS	MS	F-Ratio	P
Material	4	476.58	119.14	33.89	<.001
Layers	1	2657.39	2657.39	755.91	<.001
Material × layers	4	255.76	63.94	18.19	<.001
Error	70	246.08	3.52		

limits of RTP are provided in Figure 6 for the materials studied at each layering configuration. For each material, the single layer gave a higher RTP than the double layer (P<.001). For the single-layer configuration, material P had higher RTP values than every other material (P<.001), and material T had lower RTP values than every other material (P<.001).

DISCUSSION

This study found significant differences in color and translucency among 5 ceramic substrate systems when studied in single layers. Perceivable and often unacceptable differences in color were also found among these materials when layered with porcelain. Therefore, the null

hypotheses were rejected, and it is concluded that basic esthetic appearance characteristics of restorations that use a ceramic substrate will be affected by the ceramic system.

The sample size has varied between 5 and 10 in similar studies.[5,33] A total of 80 specimens (n=8/subgroup) was used in the present study, with half of the specimens in each material group veneered. Considering previous studies and the highly statistically significant effects found in this study, the sample size used here was reasonable and effective.

The core material thickness affects optical properties of dental ceramics. In general, the translucency of esthetic materials decreases as the thickness increases.[5,9,10] The effect of material thickness on translucency and masking ability of dental ceramic should also be evaluated. However, the specimen thickness in this study was selected to simulate clinical thickness to make the study more clinically relevant. Core specimens were 0.5 mm thick, whereas veneer ceramic thickness was 1 mm. Veneered specimens had a total thickness of 1.5 mm. Evaluating the effect of ceramic thickness on optical properties was beyond the scope of this study.

The results of the present study are in accordance with the work reported by Heffernan et al[5] who
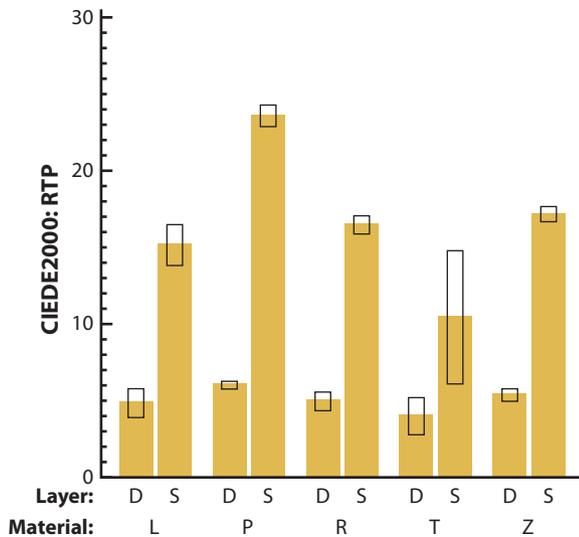
Figure 6. Means of RTP for materials studied at each layering configuration. Open rectangles provide 95% confidence limits about respective means. RTP, relative translucency parameter.

evaluated the translucency of 6 different ceramic core materials. Zirconia with a thickness of 0.5 mm was not translucent, and the opacity was similar to that of metal alloy.[5] However, the results reported by Baldissara et al[6] were contradictory, as they reported zirconia as being translucent.

Ceramic disks with A2 shade have been used in other studies.[5,33] Specimens used in the present study were A1 according to the Vita Classic color scale. Translucency and masking ability is affected by the ceramic color. A future study should evaluate the effect of different ceramic colors on translucency and masking ability.

Resin cement is commonly used for ceramic restorations.[36] Cementation with resin affects the final color perception and the clinical success of the restoration. Comparing the optical properties of the ceramic materials was in the scope of the present study. Therefore, resin cementation was not applied.

Glaze is another factor that affects the translucency and color properties of completed ceramic restorations.[34] Specimens used in the present study were not glazed because glazing is a technique-sensitive procedure that could have affected the final optical properties. Heffernan et al[34] reported a decrease in contrast ratio of all glazed ceramics other than In-Ceram Zirconia. The decrease was linked to the declined scattering in glazed specimens. To eliminate the effect of glazing on optical properties of the materials, no glazing was performed on the specimens used in the present study. However, glazing should be considered for future research.

Different parameters including grain size, additive materials, and sintering conditions can affect the translucency of zirconia.[8] Phase transition is affected when the grain size of zirconia is smaller than 2 μm. The present study did not evaluate the effect of microstructure, grain size, or phase transition on the translucency of zirconia. Correlation of the microstructure with the translucency should be evaluated in a future study.

In the process of measuring translucency, the exact colors of the black and white backings are also important. A reflectance theory can be used to account for any variation in thickness and the backings used[21,22] so that the data may be compared among researchers using differing thickness values, backings, or both. Reflectance theory has also been shown effective when applied to double layers, in which optical uniformity exists within each layer.[11] Such modeling would allow for optical characterization over a range of thickness values for a single layer[10] or for ranges of thickness values for double layers. Further examination of the modeling of optical properties of the studied materials as a function of thickness, both in single and double layers, is highly recommended because such modeling would allow for optical characterization under a range of backing and thickness variations.

In the present study, the translucency values were determined using the RTP values derived from colors of specimens in optical contact with black and white backings that are not ideal. The clinical interpretation of TP varies depending on where the esthetic restorative material is used. When the background dentin in a clinical situation is the same as the restorative material used, translucency changes on the material may be less noticeable. However, perceptible translucency differences are seen when the material is evaluated on backgrounds of differing colors and then also in the incisal and interproximal regions. The masking feature in ceramic restoration applications is a desirable feature in situations that will affect the final color of the restoration, such as discolored teeth or metal posts.

CONCLUSIONS

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

1. Significant differences were found in both color and translucency among 5 ceramic substrate systems when studied in single layers.
2. Perceivable and often unacceptable differences in color were also found among these materials when layered with porcelain.
3. The esthetics of restorations that use a ceramic substrate are notably affected by the ceramic system used.

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