Effect of Veneering Techniques on Color and Translucency of Y-TZP

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Abstract

Purpose: This study compared the color parameters and total luminous transmittance of disc specimens by different veneering techniques in order to examine the effect of veneering technique on esthetics of yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) all-ceramic restorations.
Materials and Methods: Thirty disc specimens (10-mm diameter, 0.50 ± 0.01 mm thick) were fabricated of IPS e.max ZirCAD core material, and ZL1 IPS e.max ZirLiner (0.10-mm thick) was layered. The specimens were randomly divided into three groups ($n = 10$/group). Group ZP (fully anatomical technique) was veneered 0.60 mm by heat-pressing IPS e.max ZirPress fluorapatite glass-ceramic ingots; Group ZC (traditional layering technique) was veneered 0.60 mm by condensing and sintering IPS e.max Ceram low-fusing nano-fluorapatite veneering porcelain; Group ZPC (cutback technique) was veneered by partially pressed ingots and subsequently layered 0.30 mm with veneering porcelain. Color parameters (L^*, a^*, b^*) and total luminous transmittance (τ) of zirconia core discs and core and veneer specimens were measured with ShadeEye NCC dental colorimeter and spectrophotometer, respectively. Color saturation (C^*ab) and color difference (ΔE) were calculated using color difference formula. One-way analysis of variance (ANOVA) combined with a Tukey multiple-range test were used to analyze the data ($\alpha = 0.05$).
Results: As to ZP, ZPC, and ZC groups, the value of a^* increased (-1.35 ± 0.07, -0.64 ± 0.06, -0.36 ± 0.05, respectively) ($p < 0.05$); b^* decreased (27.01 ± 0.07, 25.48 ± 0.11, 23.28 ± 0.25, respectively) ($p < 0.05$); and C^*ab decreased (27.04 ± 0.08, 25.49 ± 0.11, 23.28 ± 0.25, respectively) ($p < 0.05$). L^* value and total luminous transmittance were highest in ZP group (87.53 ± 0.48, 1.64 ± 0.03, respectively), and lowest in ZPC group (82.14 ± 0.18, 1.47 ± 0.01, respectively) ($p < 0.05$).
Conclusions: Y-TZP all-ceramic restoration veneered by fully anatomical technique was the most transparent and lightest, while restorations veneered by cutback technique were the least translucent and the darkest.

Since the introduction of Al_2O_3-reinforced feldspathic porcelain in 1965,[1] new materials and processing technologies for all-ceramic restorations with significantly improved mechanical and physical properties have been available.[2] Computer aid design/computer aid manufacture (CAD/CAM) technology has been used to fabricate infrastructures of all-ceramic restorations. Partially sintered yttrium zirconia blocks can be milled according to the frameworks designed by CAD software. Then, after fully sintering at the second high temperature, outstanding mechanical properties, such as high flexural strength and fracture toughness of a yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) ceramic, are achieved, so that Y-TZP all-ceramic restorations possess superior fracture resistance to withstand occlusal force;[3] however, since Y-TZP substructure lacks color properties and offers less light transmission, it is necessary to veneer its surface to ensure the esthetic value of restorations. The esthetics of a dental ceramic restoration is partially influenced by translucency and color.[4]

To achieve natural appearance of all-ceramic restorations, it is necessary to incorporate layers of porcelain of different opacity and shade. As a result of different composition, core materials for all-ceramic restorations come in different degrees of translucency or opacity.[5,6] The core translucency or opacity has been identified as one of the primary factors controlling esthetics and a critical consideration in the selection of the materials.[7,8] Y-TZP is placed midway among the most translucent

Empress 2 In-Ceram Spinell and the most opaque In-Ceram Zirconia.[9]

Several veneering techniques, such as traditional layering technique (veneered by condensing and sintering veneering porcelain), fully anatomical technique (veneered by heat-pressing fluorapatite glass-ceramic ingots), and cut-back technique (veneered by partially heat-pressing and subsequently layering), can be applied on IPS e.max ZirCAD core material in the IPS e.max® all-ceramic system. Each technique is said to be able to improve the esthetic properties of Y-TZP restorations; however, it has not been determined whether different veneering techniques have the same influence on the appearance of all-ceramic restorations.

The purpose of this study was to use the disc specimens fabricated of IPS e.max ZirCAD core material veneered by different techniques to investigate the effect of veneering techniques on color and translucency of Y-TZP all-ceramic restorations.

Materials and methods

IPS e.max® all-ceramic system (Ivoclar Vivadent, Schaan, Liechtenstein) was selected to fabricate specimens according to manufacturer's recommendations. IPS e.max ZirCAD block (partially sintered zirconium oxide stabilized with yttrium oxide) was the core material, while MOA2 IPS e.max ZirPress (fluorapatite glass-ceramic ingot) for heat-pressing and A2/TI1 IPS e.max Ceram (low-fusing nano-fluorapatite dentin porcelain) for layering were veneering materials. ZL1 IPS e.max ZirLiner was used as bonding ceramic. The disc specimen was composed of 0.5 mm Y-TZP core material, 0.1 mm bonding ceramic, and 0.6 mm veneering. The thickness was gauged with a digital electronic caliper (Beijing Measuring Equipment Ltd, China) with a precision of 0.01 mm on four central axes. This experimental design yielded three groups (Table 1), each containing ten specimens. Color parameters and total luminous transmittance (τ) were measured with ShadeEye NCC dental chromometer (Shofu Dent Co., Kyoto, Japan) and spectrophotometer (Shanghai Optical Instrument Factory, China), respectively.

Thirty discs, (12.5-mm diameter, 0.65-mm thick) were prepared from IPS e.max ZirCAD block using a slow-speed diamond saw (ISOMET, Buehler Ltd, Lake Bluff, IL) under a constant flow of water, which served as a lubricant and coolant. The specimens were rinsed to remove residue, and dried prior to the sintering procedure. A high-temperature furnace (Sintramat furnace, Ivoclar Vivadent) was used for the full sintering process, resulting in approximately 20% shrinkage. The zirconium oxide discs were placed in the furnace and sintered at 1500°C for 7 hours. Each specimen was embedded in acrylic resin, and ground with an apparatus (MPD-1; Beijing Experimental Equipment Ltd, China), using a series (#240, #400, #600) of alumina oxide papers in running water, then polished with lapping compound (5μm, 2.5 μm, 0.5 μm) to metallographic standard. The zirconium oxide core discs (group Z) were 0.50 ± 0.01 mm thick and 10 mm in diameter.

All group Z specimens were ultrasonically cleaned in distilled water for 10 minutes and dried to be free of dirt and grease. ZL1 IPS e.max Ceram ZirLiner was mixed with build-up liquid (Ivoclar Vivadent) to a creamy consistency, then layered on the core specimens, vibrated to achieve an even, greenish color effect, and finally fired. The IPS e.max ZirLiner should have a layer thickness of approximately 0.1 mm.

For group ZP (veneered by fully anatomical technique), wax patterns 10 mm in diameter and 0.8 mm in thickness were fabricated on ZirLiner layer by placing wax in a vinylpolysiloxane putty mold. The wax patterns were invested with a proprietary investment material (IPS PressVEST Speed Investment; Ivoclar Vivadent) and hot-pressed with MOA2 IPS e.max ZirPress ingot (Ivoclar Vivadent) in EP500 hot-pressing furnace following the manufacturer's instruction. The white reaction layer was carefully removed from the casts by Al_2O_3 at 1 bar. The specimens were embedded, ground, and polished to the ultimate thickness of 1.20 ± 0.01 mm.

For group ZC (veneered by traditional layering technique), the veneering process began with a wash firing. Dentin porcelain powder (A2/TI1 IPS e.max Ceram) was mixed with all round build-up liquid. A thin but complete coat was applied on the entire surface of ZirLiner. The dentin porcelain slurry was condensed with vibration, and excess moisture was removed with paper tissue to minimize porosity. Group specimens were fired together in the sintering furnace (Multimat Touch & Press; Dentsply Ltd, York, PA) at 750°C for 1 minute. The addition of porcelain and a second dentin firing cycle was carried out to compensate for peripheral shrinkage of the initial veneering porcelain. Finally, the discs were ground and polished on the veneer side to the designated thickness of 1.20 ± 0.01 mm.

For group ZPC (veneered by cutback technique), wax patterns 0.50-mm thick were fabricated on the ZirLiner layer, then invested, preheated, and hot-pressed with MOA2 IPS e.max ZirPress ingots. The investment ring was bench cooled and divested. The specimens were embedded and ground on the veneer side to the thickness of 0.90 ± 0.01 mm. After a wash firing with A2/TI1 IPS e.max Ceram dentin powder to form a thin bonding ceramic layer on the hot-pressed veneer, the dentin porcelain slurry was applied, condensed, and fired. The second dentin firing cycle was also carried out to compensate for peripheral shrinkage. Finally, the discs were

Table 1 Core, veneer thickness, and total thickness of groups

Group	IPS e.max ZirCAD (mm)	IPS e.max ZirLiner (mm)	IPS e.max ZirPress (mm)	IPS e.max Ceram (mm)	Total (mm)
ZP	0.50 ± 0.01	0.10 ± 0.01	0.60 ± 0.01		1.20 ± 0.01
ZPC	0.50 ± 0.01	0.10 ± 0.01	0.30 ± 0.01	0.30 ± 0.01	1.20 ± 0.01
ZC	0.50 ± 0.01	0.10 ± 0.01		0.60 ± 0.01	1.20 ± 0.01

ground and polished on the veneer side to the total thickness of 1.20 ± 0.01 mm.

The procedure resulted in the flat surface required for the measurement. Specimens were ultrasonically cleaned in distilled water for 10 minutes, and the ultimate thickness was checked.

Color parameters of core discs and core-veneer specimens were measured in the "Analyze Mode" of ShadeEye NCC (Shofu), a tri-stimulus chroma meter with pulse Xenon Lamp as optical light source and vertical light receiving system. The color was registered regardless of the presence of ambient light, eliminating the effect of outside variables such as light sources and background differences on shade taking, so as to allow for objective and predictable color determination. The color of the specimen was measured against a neutral gray background ($L^* = 90.53$, $a^* = 0.57$, $b^* = -5.70$). Before each group of color measurements, the instrument was calibrated against a standard calibration to ensure reliability. The contact tip (3-mm diameter) was positioned in the center of the disc, and the optical measuring area fully contacted the surface. Correct measurement depends on the position and angle of the contact tip. If there were significant differences between measuring results, the measurement was repeated. The data were then transmitted to the ShadeEye View software and expressed in terms of three coordinate values (L^*, a^*, b^*), which were established by the Commission International de I'Eclairage (CIE)[10] for the purpose of quantifying the appearance of an object. L^* represents the luminance of the color (or value) on a numerical scale from zero (black) to 100 (white). The color coordinates a^* and b^* represent a position between red (+a) and green (−a) and between yellow (+b) and blue (−b). The values of the L^*, a^*, b^* color coordinates were determined from three measurements of the center of the disc. Color saturation (C^*ab) of each specimen and color difference (ΔE) between groups were calculated by the following formulae:

$$C^* ab = \left[(a^*)^2 + (b^*)^2\right]^{1/2}$$

$$\Delta E = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2}$$

ΔL^*, Δa^*, and Δb^* represent the differences in CIE color-space parameters of the two colors.[11,12]

Each specimen was positioned in the spectrophotometer for the total luminous transmittance test in the visible spectrum with wavelength between 380 and 780 nm. Three numerical readings were taken for each specimen,[13,14] with the angle of incidence and reading at 0/0[15] and at an interval of 10 nm. The consecutive T values of direct transmittance in the range of 380 nm to 780 nm were transferred to Microsoft Excel for quantitative analysis.[14,16-18] The total luminous transmittance (τ) was calculated using an integral equation concerning T (λ) (the direct transmittance at individual wavelength), S (λ) (the relative spectral power distribution), and V (λ) (the spectral luminous efficiency). The ultimate τ is an integral result of the total luminous transmittance in the visible spectrum for each specimen. One-way ANOVA combined with a Tukey multiple-range test were performed to compare L^*, a^*, b^*, C^*ab, and τ values of the groups by SPSS 10.0 (Statistical Product and Service Solutions, SPPS Inc, Chicago, IL, USA) ($p = 0.05$).

Results

Table 2 shows the mean values and corresponding standard deviations (SDs) of color parameters and τ values as determined by the colorimeter and spectrophotometer. One-way ANOVA identified significant differences in transmittance (τ) between groups using different veneering techniques. The transmittance of group ZP was statistically significantly higher than group ZC, while group ZPC was the least translucent. After veneering, transmittance significantly decreased, regardless of veneering technique.

Significant differences were also found in the color parameters. For groups ZP, ZPC, and ZC, a^* value increased, and b^* and C^*ab values decreased in turn. Group ZP was significantly lighter than groups ZC and ZPC, while the L^* value was the lowest in group ZPC. Compared with core discs, veneering resulted in significant reduction in L^* value and transmittance and increase in b^* and C^*ab; however, no significant difference was recorded for a^* values.

Calculated mean color difference (ΔE) values were much higher than 1 ΔE unit in groups by different veneering techniques. No matter which veneering technique was carried out, the mean color differences were above perceptibility and acceptability thresholds (Table 3).

Discussion

Color and its elements, such as hue, value, chroma, translucency, opacity, light transmission and scattering, metamerism, and fluorescence, influence the esthetics of a dental restoration.[19] All-ceramic restorations fabricated of core materials with corresponding veneering ceramic provide both excellent physical and esthetic properties. To effectively use techniques

Table 2 Mean color parameter (L^*, a^*, b^*, and C^*ab) values and τ values along with SDs as determined by tri-stimulus colorimeter and spectrophotometer (n = 10/group)

Group	Color parameter				Transmittance τ
	L^*	a^*	b^*	C^*ab	
Z	94.51 ± 0.10	−1.31 ± 0.17	2.19 ± 0.63	2.55 ± 0.63	2.29 ± 0.06
ZP	87.53 ± 0.48	−1.35 ± 0.07	27.01 ± 0.07	27.04 ± 0.08	1.64 ± 0.03
ZPC	82.14 ± 0.18	−0.64 ± 0.06	25.48 ± 0.11	25.49 ± 0.11	1.47 ± 0.01
ZC	84.24 ± 0.10	−0.36 ± 0.05	23.28 ± 0.25	23.28 ± 0.25	1.54 ± 0.03

Table 3 Mean color difference (ΔE) values between groups with different veneering techniques and between core discs and veneered specimens

Groups	ΔL*	Δa*	Δb*	ΔE
ZP-ZPC	5.39	0.71	1.53	5.65
ZP-ZC	3.29	0.99	3.73	5.07
ZPC-ZC	2.10	0.28	2.20	3.05
ZP-Z	6.98	0.04	24.82	25.78
ZPC-Z	12.37	0.67	23.29	26.38
ZC-Z	10.27	0.95	21.09	23.48

for all-ceramic restorations, clinicians and technicians should know whether esthetics are affected by the veneering technique.

Although the high flexural strength and fracture toughness of yttria-stabilized zirconia ceramic result in the superior fracture resistance of all-ceramic restorations, the Y-TZP-based system uses a white-colored core, which may reduce the restoration's esthetics.[20] Therefore, veneering is necessary to ensure the esthetic effect.[21,22] Three types of procedures are clinically used to veneer zirconia core: the traditional layering technique (veneered by condensing and sintering veneering porcelain), fully anatomical technique (veneered by heat-pressing fluorapatite glass-ceramic ingots), and cutback technique (veneered by partially heat-pressing and subsequently layering).

Dentin porcelain for layering technique contains nano-fluorapatite crystals similar to those of vital teeth, which ensure the restorations match natural tooth accurately in terms of color, surface texture, and translucency. Ingots for the heat-pressing procedure can either be fully anatomically pressed or just pressed in a dentin core in cutback technique. Due to the ingot delivery form, an improved homogeneity (porosity and bond) is achieved. The different-sized fluorapatite crystals control the relationship between translucency, opalescence, and brightness of the restorations.

Influence of veneering techniques on the translucency of Y-TZP restorations

The ultimate translucency of the core-veneer system is important for optimal esthetics.[2] The translucency of ceramics can be affected by many factors, including thickness,[5,23] crystal microstructure (crystal volume and the refractive index, particle size),[24] and the number of firing cycles.[25] An all-ceramic restoration is a multi-layered porcelain structure composed of a core and veneer.[23] In the present study, transmittance significantly decreased after veneering, regardless of veneering technique. The possible reasons for this decrease include increased specimen thickness,[26] structure of the veneering material (varied crystalline contents and higher porosity volume), and reflectance at the interface between the core and veneering material.[6]

Manipulative technique can also influence the translucency of all-ceramic restorations. Ceramists or manufacturers contend that porcelain manipulative variables cause shade variability. Several factors that affect the ability of a ceramic system to produce an acceptable match with corresponding shade guides, such as condensation techniques,[27] firing temperatures,[28] and dentin thickness,[29] have been investigated. The anterior crowns made of Empress 2 by a layering technique were less translucent than those made by a staining technique, and the ultimate color of the former was less influenced by the shade of the luting agent.[30]

The significant decrease of transmittance in groups ZP, ZC, and ZPC also suggests that the restoration is most translucent when veneered by the fully anatomical technique, followed by the layering technique; the cutback technique results in the most opaque restorations. It has been suggested that Y-TZP core material is hardly affected by additional firings after it is fully sintered, without a change of optical property.[25] Instead, the difference of translucency may be caused by veneering. Due to the homogeneity of ingots, crystals are proportionally distributed on the hot-pressed veneer without an obvious porous structure. The limitations of the layering technique, such as the ratio of porcelain/liquid, vibration and condensation techniques, and firing temperature, result in insufficient grain growth, contributing to the asymmetric size and inhomogeneous distribution of crystals and high pore volume. The present study suggests that the content and distribution of crystals and porosity vary in pressed and layered veneering, so light is reflected at the interface of the two layers fabricated using different techniques, and the light transmitted is reduced. As a result, group ZPC core-veneer specimens using a cutback technique, veneered by partially hot-pressing and subsequently layering, are the least translucent.

It is unclear whether the statistically significant differences in transmittance found in the in vitro study would impact the clinical appreciation of translucency. The visual degree of opacity can be appreciated with the various specimens over a black backing. In the oral environment, the difference might be less obvious. Further study is required to determine the amount of change in translucency the human eye can detect.

Influence of veneering techniques on the color of Y-TZP restorations

Pigments such as metal oxides are added to porcelain to enrich the color of ceramic materials, so clinically esthetic requests can be satisfied.[31] Y-TZP core material is composed of densely sintered zirconium oxide crystal (87% to 95%) and yttrium oxide (4% to 6%) as stabilizer, containing few pigments. It is quite necessary and important to fabricate veneers for a satisfactory esthetic effect of the restorations. A variety of pigments are contained in the ingots for heat-pressing and dentin veneering porcelain for layering.

In the present study, it was possible to test whether the mean values of L*, a*, and b* of one group was different from the respective mean value of another group. Since individual specimens in a group do not relate to individual specimens of another group, it is not possible to calculate changes between individual specimens of different groups. Only the mean L*, a*, and b* values of each group may be used to calculate the ΔE between groups, which means no SD is available. The color difference value (ΔE) represents the numerical distance between L*a*b* coordinates of two colors. When the $\Delta E < 1$, a color match between two colors can be judged. When color difference is within the 1 to 2 ΔE unit range, correct judgment can be made frequently by observers. When ΔE value is greater than 2 units, all observers can apparently detect color difference.[32] The clinically acceptable limit of color difference is considered to be 3.7 ΔE units.[32,33] Ragain and Johnston[34] found that observers had an equal probability (50%) of accepting or rejecting the color match of specimens at a color difference of 2.72 ΔE units. Rather than using monochromatic specimens, Douglas and Brewer[35] determined that the 50% acceptability tolerance for a group of 20 prosthodontists was between 1.7 and 2.7 ΔE units for crowns varying in yellowness and between 0.5 and 1.5 ΔE units for crowns varying in redness. They also found that the predicted color difference at which 50% of dentists could perceive a color difference (50/50 perceptibility) was 2.6 ΔE units, and when color difference was at 5.5 ΔE units, restorations were remade due to color mismatch (clinically unacceptable color match).[36]

No matter which veneering technique is adopted, b* and C*ab values increased significantly after veneering, indicating that the specimens tend to become more yellow and more colorful. Color difference before and after veneering is from 23.78 to 25.78 ΔE units, which is in the perceptible range. The result demonstrates that the veneering procedure ameliorates esthetics of Y-TZP all-ceramic restorations to good purpose. Yong-Keun et al studied the layered color of different types of all-ceramic core and veneer ceramics in clinically allowable thickness, finding that the CIE a* value of the layered specimen was primarily influenced by a* of the core, and CIE b* was primarily influenced by b* of the veneer.[37] Although aluminum oxide core discs did have a degree of masking capability, it was concluded that the resulting color of porcelain veneers could successfully be modified with the veneering porcelain.[38]

L* values, which reflect the brightness of the specimens, decrease after veneering as the total thickness of the specimen increases. This phenomenon can be explained by the increase of absorption of incident light with thicker specimens that reflect reduced quantity of light, thus lower L* values.[26,39]

Instrumental measurements can quantify color and allow communication to be more uniform and precise. In dental research, colorimetric instruments have been used extensively; however, the accuracy of measurement results is subject to edge loss errors as a result of the translucent optical property of teeth and dental ceramics.[40] Edge loss is the phenomenon that when light strikes a translucent material, a considerable portion of the light is lost through translucency and scattering, displaced in a sideways direction, never returning to the sensor for measurement. The resultant color values will therefore be affected. To determine the true colors of translucent specimens and avoid the inaccuracies of edge loss, it is recommended that the ideal optical is a 45° illumination and 0° observation configuration.[41,42] In view of the vertical light receiving system of ShadeEye NCC, the thickness of core ceramic was 0.5 mm to minimize the effect of edge loss, which is the least recommended thickness for crowns. While after veneering, the core-veneer specimens were thicker, so another reason for the decrease of L* value may be the system error resulting from obvious edge-loss phenomenon. The present study demonstrates that specimens veneered by the fully anatomical technique are lighter than those using the layering technique, and the cutback technique leads to the darkest restorations, resulting from reflectance at the interface of pressed and layered veneers.

The specimens using the fully anatomical technique tend to be yellower and the highest in color saturation; those using the layering technique are redder and the lowest in color saturation. Each ceramic system has a different color standard due to different type and microstructure. Rosenstiel et al measured color parameters (L*, a*, and b* values) of five ceramic systems, and significant differences were found between the same A2 shade of different ceramic systems.[43] Although ingots for heat-pressing and dentin porcelain for layering are the same A2 shade, there are still some differences in pigment contents. Besides, due to different infrastructure, homogeneity, and porous volume in pressed and layered veneer, differences in hue and color saturation are detected. And the color difference between restorations by different veneering techniques is detectable.

The influence of background substrate on the final appearance of the ceramic specimens is well established.[44] Abutments prepared for receiving all-ceramic restorations are not likely to be of neutral color. Should the study be on the shade matching of restorations,[29] it should include supporting structures of different color parameters, such as natural dentition and various dowel and core materials. Finally, all-ceramic restorations should be cemented to the tooth substrate with a luting agent[45] whose shade and thickness contribute to the final restorative appearance. Therefore, further studies on the interaction of the ceramic materials with luting agents and other substrate backgrounds are needed.

Conclusions

Based on the limitations of this study, the following conclusions can be made:

(1) Y-TZP all-ceramic restorations veneered by the fully anatomical technique were the most transparent, and lightest.
(2) Restorations veneered by the cutback technique were the least translucent and darkest.

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