ORIGINAL RESEARCH

In vivo Evaluation of Shade Replication of Different Generations of Zirconia to Natural Teeth Using Digital Color Determinations

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Abstract

Aim: The color difference between the final shade of restorations milled from different zirconia blocks, and the control teeth in the esthetic zone is yet uncertain.

Materials and methods: For eight patients who required a singular maxillary central incisor restoration, twenty-four crowns made of zirconia were created. These were grouped into three categories based on the shade and nature of zirconia (Zr) utilized (white core, colored core, and monolithic high-translucency (ht) Zr crowns). The difference in color (Δ*E*) between the three zirconia crowns and the neighboring teeth was calculated by the use of Easyshade spectrophotometer. Two shades of resin luting cement were used. The measured Δ*E* values were evaluated based on a clinically acceptable color difference of 1.6Δ*E*, which is not visible to the human eye.

Results: Among the three groups, no differences of statistical significance were observed in terms of Δ*E* with different Zr types and resin cement color.

Conclusion: Within the limits of this study, the usage of different shades of zirconia blanks and resin cements did not display a statistically significant effect on the final color of the crown.

Clinical significance: Changing the shade of resin cements does not appear to add value to the final shade of crown. In addition, the generation of zirconia does not influence the shade of the crown. Crowns made of zirconia can be cemented with opaque or transparent cement with no effect on the final color.

Keywords: Delta E, Easyshade, Resin cement, Spectrophotometer, Zirconia.

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Introduction

In the field of esthetic dentistry, the reproduction of teeth color is a major challenge. Clinicians now have to meet higher standards and expectations for precise color matching as patients place more emphasis on esthetics. The success of an esthetic crown is now much more dependent on accurate color matching.[1]

Zirconia crowns for incisors were created in response to patients' needs for extremely esthetic crowns and developments in prosthetic manufacturing procedures.[2] The interaction of two significant optical elements results in an all-ceramic esthetic restoration that exactly complements neighboring teeth: the measure of the ceramic's translucency that would permit the natural background color to show through a translucent material and the ability of ceramics to block the abutment shade with adequate ceramic bulk or an opaque hiding liner. Modern ceramics made of high-strength zirconia, which combine the advantages of all-ceramic crowns, show excellent clinical results and superior esthetics. It has been claimed that various zirconia substructures could enhance the esthetic outcomes of zirconia ceramic crowns.[3] But, with veneered all-ceramic crowns in which there is more than one layer with different thicknesses, the final color outcome is unknown.[4] Yet, color assessment and reproduction are two of the more difficult components of esthetic dentistry. This mentions the dental ceramics' ability of reproducing the shade of the targeted shade tab without the use of internal or external colorants.[5]

In addition to the preparation's color, the selected crown color and the resin cement color affected the finished ceramic crown shade. To replicate natural crown color, these three elements must be visually balanced. Excellent color matching should be properly translated to the clinical situation, assuming it has been verified in the dental laboratory.[6] Zirconia frameworks are naturally white, which may have a negative impact on the veneered restorations' ultimate esthetic appearance. Due to this, such restorations could only be used in the posteriors.[7]

Although high-strength ceramics may have greater opacity and need additional tests when attempting to counterpart natural

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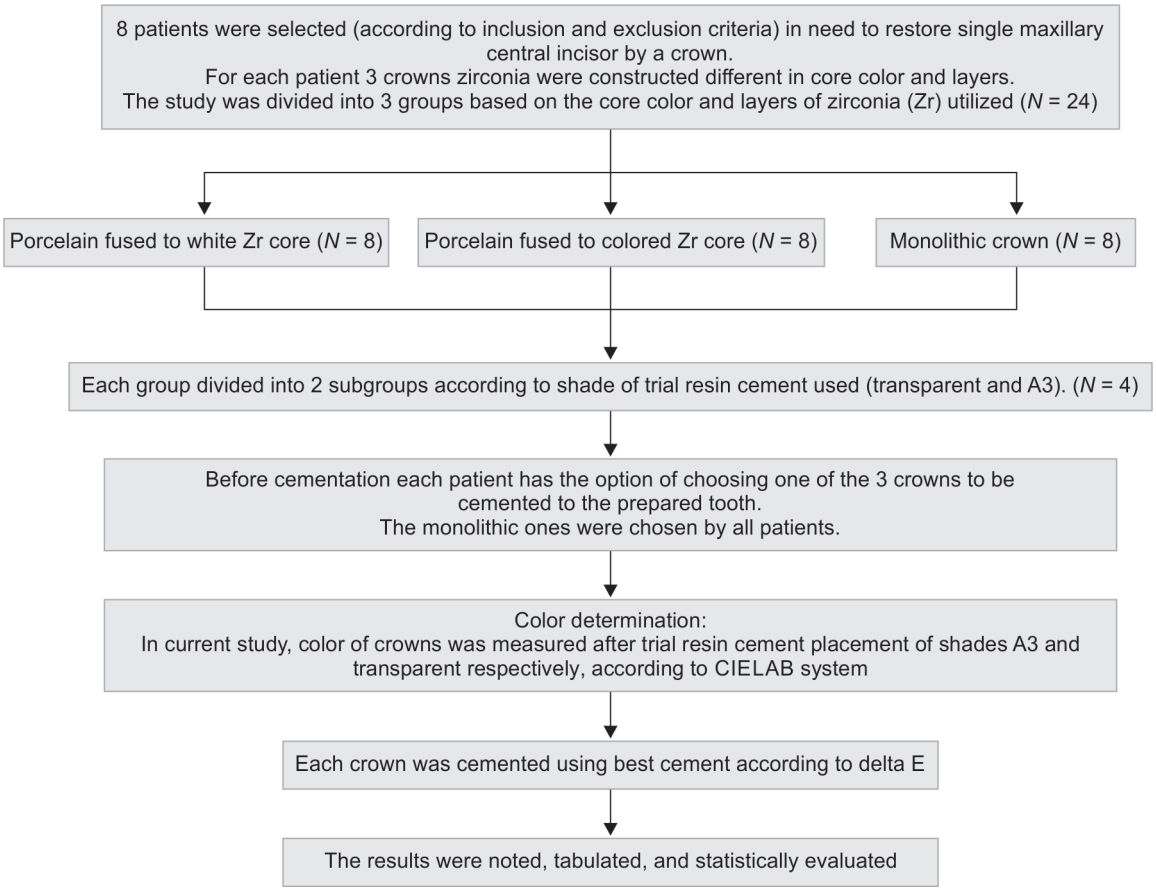
Flowchart 1: Flowchart of study steps



teeth shade, they can be utilized to conceal discolorations that are already present, according to the literature.[8] In order to improve the color reproduction of ceramic restorations, the dental market saw an introduction of colored zirconia frameworks, especially in situations where there is not enough room for both the framework and the ceramic veneer to be of the requisite thickness.

But, in order to get the desired final hue, the veneer-application process needs to be adjusted for these new colored frameworks. The color of the zirconia has an impact on the strength of bonding in between the framework and ceramic veneer.[9] To accurately match shades, three key components of color hue, chroma, and value must be present. Yet, a fourth component, translucency, has emerged as a crucial feature in the precise determination of shade matching.[10]

Monolithic high translucent zirconia was introduced, with the potential to match and even outperform lithium disilicate in strength. Whole contour crowns can be machined from this material. Additionally, there are no recommendations for using various cement hues in clinical settings. A question worth answering is which zirconia core is better to use and can we prevent the increased expense of colored cores and their laborious steps of manipulation? Does the production of esthetically pleasing crowns really depend on the expertise of the laboratory technician, or do translucent zirconia blanks play a role? Why does the cement color affect the ultimate shade of the crown? The study's hypothesis was that the various zirconia frameworks (white, colored, and monolithic) would have variable color differences (ΔE) with respect to the control teeth.

Materials and Methods

Study Design

This study was designed according to the CONSORT 2010 clinical trial guideline. This is a randomized, controlled, single-blind (patient), cross-sectional, experimental, clinical trial.

Study Setting

Patients were chosen from the Outpatient Clinic at the Faculty of Dentistry, Beirut Arab University, Lebanon. They wanted to place one single ceramic crown on any of their upper incisors. The patients had the knowledge of the scheme of the clinical study, and agreement was achieved previous to treatment. The design of the study was recognized by the IRB committee at BAU (2014H-003-D-P-0012). The study was conducted in 2021 for one-year duration. Ceramic crowns were labeled and placed in identical boxes; therefore, the patients were blinded to the crown being chosen and delivered.

Study Sample

The sample size was calculated by the G Power software. With a 95% confidence interval, an 80% power, and an effect size of 80%, a sample size of $n = 24$ (8 in each group) was necessary. The sample size was adequate for evaluation statistically and in line with Consort 2010 sample size determination (Flowchart 1). Eight patients were nominated and recruited depending on the following:

Table 1: Grouping of samples

Group	*Color of core and layers of zirconia*	*Subgroup*	*Resin shade tried*	*N*
VW	Veneered with white cores crowns	VWT	Transparent	8
		VWA	A3	
VC	Veneered with colored core crowns	VCT	Transparent	8
		VCA	A3	
M	Monolith crowns	MT	Transparent	8
		MA	A3	
		Total number of crowns		24

Inclusion Criteria

- Recommended for one of their upper incisors with a single all-ceramic crown (no canines).
- At least one of the nearby teeth might be used as a reference point and a control to determine the shade.
- Minimally invasive proximal fillings that do not impair the esthetic appearance of the buccal area were allowed.
- Good oral hygiene and knowledge.

Exclusion Criteria

- Patients with extensive carious teeth that had to be crowned.
- Patients with no single adjacent sound teeth.
- Unmotivated patients that could not perform oral hygiene measures.
- Patients with any periodontal problem that might complicate the procedure.
- Canines for their bulkiness.

Sample Grouping

Twenty-four ceramic crowns were constructed and assigned to three groups according to color of the core and number of layers into Group VW: veneered with white cores crowns, Group VC veneered with colored cores crowns, and Group M: monolith crown. Each group was additionally divided into two subgroups based on the color of resin cement (T: transparent color and A: A3 color).

Three crowns (one of each group) were assigned for each patient. Each crown was tried with either trial cement or shade-recorded (two shade recordings for each crown according to trial cement used). Delta *E* was calculated between each crown and between each trail cement used with natural teeth as a control. The patient then chooses one crown according to his perception and cemented with either transparent cement or A3 according to which one with smaller delta *E* compared with natural teeth (control) (Table 1).

Baseline Shade Recording

With the usage of a rubber polishing cup at a low pace and basic white dentifrice, all teeth were cleaned and polished. The target neighboring teeth was employed as the control shade, so an intraoral spectrophotometer (Easyshade V, Vita; Yorba Linda, North America) was employed to record colors for the central incisor that would undergo restoration and the control teeth before preparation. Every teeth had spectrophotometric examination at 1.5-mm-diameter circular areas on its labial surface with the tip of the probe held at an angle of 90° to the teeth's surface.[11] The probe was not moved during the measuring process or put at a different angle. A caliper was used to identify the middle position of the labial surface and to pinpoint the precise location.[12] Based on the CIE-Lab system, the standardized circular area's color was quantified and expressed using the L*, a*, and b* color coordinates.[13]

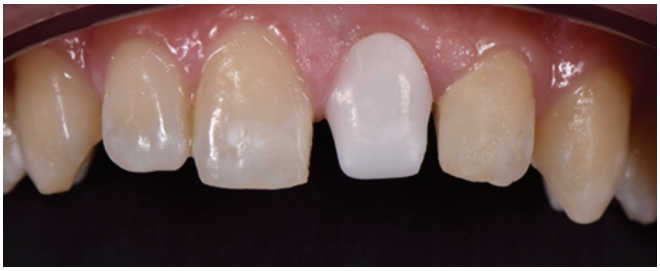


Fig. 1: Try-in of white zirconia core

Data were gathered three times. The entire procedure was then performed for the neighboring teeth after another calibration cycle.

Teeth Preparation for Crown Restoration

For each patient, three silicon indexes were created: one for incisal and axial teeth reduction control, one for creating an appropriate provisional restoration, and one for sending to the lab to duplicate the entire crown contour.

Using a round end-tapered guided-pin diamond bur, a 0.9 mm subgingival heavy chamfer finish line, 1.2 mm of axial reduction, and 1.8 mm incisal clearance were created.[14] With guided-pin finishing burs, the preparations were finished to guarantee a smooth final surface.

Provisional Restoration

A temporary dental cement devoid of eugenol was used to paste the provisional resin material, which was inserted into the prefabricated index and covered the preparation until it had time to set.

Final Impressions and Crown Construction

In another visit, final impressions were done to allow adequate time for periodontal health and to mold the gingiva during interim restoration in order to stop bleeding during the placement of the retraction cord employing a double cord for gingival displacement.[15] They were scanned with a Cercon eye scanner after type-IV stone was poured, and precise dyes were created. Each patient was given three zirconia crowns.

Zirconia blanks were milled into copings of zirconia and monolithic crowns, which were then sintered in accordance with the manufacturer's specifications. Using a Cercon base light blank, a white zirconia core of 0.5 mm thickness for group I was machined. Using the Cercon base colored blocks, a 0.5 mm colored core made of zirconia was machined for group II. Using Type-0 Cercon brain expert cutters, the entire full-contour monolithic highly transparent crowns made of zirconia for group III were fabricated from Cercon ht blanks and heated in a furnace at 1.500°C.

After sintering, the copings' inner and outer surfaces were manually finished for the three groups using air particle abrasion and 100-alumina particles.

Try-in

Trial fittings were done for each coping and crown on the corresponding teeth (Figs 1 to 3).

Cleaning was done with a steam cleaner. L, a, and b color parameters of every crown/coping were measured with the help of Easyshade V.

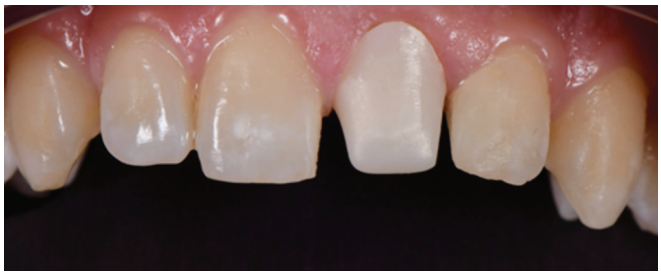


Fig. 2: Try-in of colored zirconia core

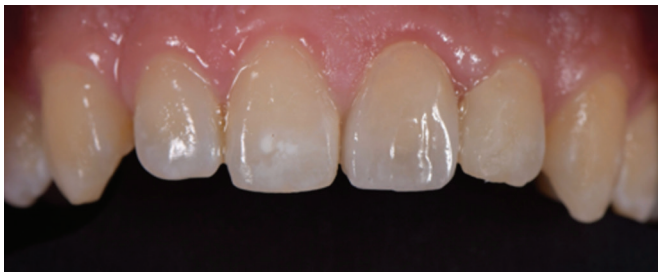


Fig. 3: Try-in of monolithic crown

For group III, crowns were externally stained with body stains, while for groups I and II, feldspathic ceramic (Cercon CeramS) veneering was utilized for copings.

Before being glazed, completed crowns were successively tested on the corresponding preparation to ensure adequate fit, contacts, and occlusal adjustments (if necessary).

Try-in and Cementation

These are options for selecting one of the three crowns for final cementation. The monolith full-contour crowns were chosen by all patients, likely due to their small weight.

Before applying zirconia primer, air particle abrasion with 100 Al_2O_3 was done to all intaglio surfaces. By using resin cement, proper cementation operations were completed (Multilink Automix, Ivoclar Vivadent AG, Schaan, Liechtenstein).

Color Determination

In our study, the color parameters L, a, and b of every crown were measured first with the addition of trial A3 resin cement, and second with the addition of a transparent one. D65 was the regular illumination used with a light spectrum range of 360 and 740 nm. The color of each group in the experiment was measured in three coordinate dimensions of L* from 0 (black) to 100 (white), a* green–red (–a* = green; +a* = red), and b* blue–yellow (–b*=blue; +b*=yellow). The cervical, body, and incisal regions' areas of interest were measured as 3 × 3 mm squares. The results were calculated using average readings from the triplet measurements. The adjacent target teeth's color information was used as a control. The following formula was used in determining the difference in color between the crowns of zirconia and the control (neighboring teeth).

The difference in color Δ*E* between the control (adjacent teeth) and the color of zirconia crowns was calculated as follows:

- Δ*L**= (L*control – L*experimental)
- Δ*a**= (a*control – a*experimental)
- Δ*b**= (b*control – b*experimental)

Table 2: Descriptive statistics of color change (Δ*E*) of different groups and subgroups

Subgroup	*Mean ± SD*	*Minimum*	*Maximum*
VWT	1.23 ± 0.66	0.36	2.17
VWA	1.20 ± 0.47	0.54	1.87
VCT	1.40 ± 0.92	0.30	2.98
VCA	1.37 ± 0.87	0.23	2.93
MT	1.47 ± 0.76	0.42	2.81
MA	1.50 ± 0.70	0.51	2.76

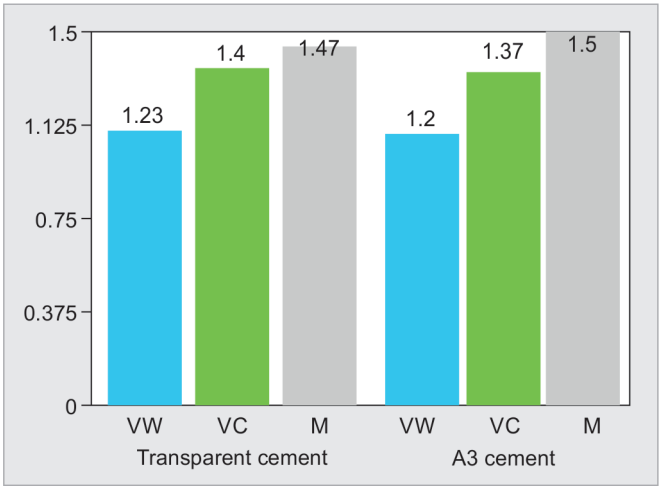


Fig. 4: Bar chart representing mean (Δ*E*) values between subgroups

- Δ*E**= (Δ*L**2 + Δ*a**2 + Δ*b**2)1/2
- The Δ*E*'s achieved were assessed based on Δ*E* of 1.6 which represented the color difference that is not detectable by the human eye and considered as clinically acceptable.[6]

Statistical Analysis

Recorded data were coded and analyzed using descriptive statistics (mean and standard deviation) for quantitative variables. Data recorded were found to be normally distributed according to Shapiro–Wilk test. Significant differences between groups were determined using parametric one-way ANOVA test conducted to analyze the differences Δ*E* of crowns using two trial cement colors. Therefore, *p*-values equal to or less than 0.05 were considered statistically significant. Statistical analysis was performed using IBM SPSS Statistics Version 20 for Windows.

Results

Shapiro–Wilk Test, using a Right-tailed Normal Distribution

The test was run on both groups to determine the homogeneity of specimens' results. This decides the statistical analysis implemented. The results of the test showed that the data were normally distributed.

Descriptive Statistics

Analysis showed higher mean values of MA subgroup (1.50 ± 0.70) followed by MT subgroup (1.47 ± 0.76). The least was subgroup VWA (1.20 ± 0.47) (Table 2 and Fig. 4).

Table 3: Comparison between color difference (Δ*E*) of different groups

	VW	*VC*	*M*	
Cement	*Mean ± SD*	*Mean ± SD*	*Mean ± SD*	*p-value*
A3 cement	1.23 ± 0.66	1.40 ± 0.92	1.47 ± 0.76	0.882
Transparent cement	1.20 ± 0.47	1.37 ± 0.87	1.50 ± 0.70	0.882

Results were insignificant; $p > 0.05$

One-way ANOVA Test

Application of one-way ANOVA test revealed that there were no differences of statistical significance between the studied groups ($p = 0.882$) (Table 3).

Discussion

An incisor was selected for this study because, in terms of esthetics, it presents the biggest difficulty for clinicians in terms of restorative care; unsurprisingly, it is the most difficult teeth for a ceramist to equalize.[16] Due to its favorable mechanical properties, zirconia was selected as the material of choice. Moreover, it has superior stress-induced toughening mechanism and confirmed biocompatibility.[17] For several Zr cores, spectrophotometric color measurements were reported using the L*, a*, and b* color coordinates of CIE. The difference in color value (Δ*E*) represented the numerical difference of two colors with coordinates of L*, a*, and b* each.[15]

The aim of this study was to determine the difference in color between the restoration and the natural control teeth and to assess the capability of various crowns fabricated from zirconia blanks of different shades to copy the specific shade of the next teeth.

Scientists evaluated how different thicknesses of dentin ceramics and multiple firings may have impacted their findings. Because color was the only variable and ceramic thickness remained constant across all groups in the current study, it was possible to attribute differences in color coordinates to those differences in color alone. Moreover, the number of firings was not a studied variable.

Descriptive statistics of Δ*E* values of the different groups were recorded regarding the mean, standard deviation, and minimum and maximum values.

There was no significant difference between veneered white core zirconia, veneered colored core zirconia, and translucent full-body monolithic zirconia. Δ*E* numbers were statistically insignificant between the control group and various zirconia crowns. The mean Δ*E* values were 1.22 for Gr I, 1.30 for Gr II, and 1.34 for Gr III.

The differences in Δ*E* values between the control group and the various zirconia crowns were not statistically significant. Though the Δ*E* numbers in the present investigation were in perceptible variety described by Seghi et al. in 1989 (1–2), it should be highlighted that this may not have clinical significance in terms of color perception.[18] The Δ*E* values were below the acceptable range as is reported by Ishikawa-Nagai et al. in 2009 (1.6), which explains why.[1] This variation in Δ*E* values among the different combinations, along with the absence of statistically significant differences in color parameter comparisons, suggests that the effort typically expended to replace the boring white core with metallic oxides and dip-in solutions may not have been entirely worthwhile. The Cercon CAD/CAM system, which has already available precolored zirconia blanks, was employed in our investigation. Before adding the veneering ceramic, as instructed by the manufacturer, no liner was utilized with the white zirconia cores. This also made it easier to overlook the impact that a liner's addition had on the last shade of the white cores of zirconia after veneering. The addition of necessary veneer ceramic above the zirconia framework produced a precise duplicate of the desired color, according to Aboushelib et al. study; however, colored zirconia needed the addition of a liner or dentin of dark chroma for achieving the desired shade.[7] The findings were consistent with this research, and the conclusion was that using frameworks made of colored zirconia did not provide one clear benefit over using white cored zirconia alone.

Also, the minimal variation in color between the monolith and the other crowns would favor choosing monolithic crowns and practicing more cautious teeth preparation. Our results were in agreement with Cui et al. study which found that anatomic contour crowns of zirconia material created by additive wet deposition were noted to be better matched to adjacent teeth and achieved excellent esthetics in the categories of color and translucency gradient.[19] In our case, no discolored stumps were included because translucent zirconia materials would become disadvantageous.[20] In our study, the restoration design was the same, so it had no effect as that found in a study done by Ghoveizi et al. in 2023, which showed that restoration design had an effect on the matching color of multilayered translucent zirconia crowns.[21] Hjerppe et al. in 2008 described a decrease in the strength of zirconia that had previously been colored with zirconia coloring liquid. They were in agreement with our study with respect to the use of colored zirconia blanks.[22]

One of the study's weaknesses was the small number of participants due to the challenge of locating individuals who needed to have a single central incisor crowned. A noteworthy distinction is that in the majority of works on color coordinates, discs were utilized as specimens,[23] whereas crowns were employed in the current investigation to simulate the proper clinical settings.

One limitation to the study was that color measurement, e.g., the Munsell Color Order System and the CIE L*a*b System, would need diffuse illumination of the whole teeth. Therefore, color studies using color measurement devices usually had to be done only *in vitro*.[24] In order to mimic a natural teeth's color gradient appearance, one possible way is through the manipulation of the coloring additives' distribution within a single zirconia block. This new esthetic zirconia block would contain several structural layers each with different coloring additives arranged in specific, desirable orders. It could be regarded as a kind of functional gradient material (FGM), where the function would refer to the esthetic property.[25]

Since no difference in color was detected between the tested groups, the hypothesis was rejected.

Conclusion

Within the limitations of the present *in vivo* study, the following could be concluded: No significant difference was recorded between different zirconia-based crowns and no perceivable color difference between any of the three zirconia-based crowns and control teeth. Resin cement shade did not have an effect on the final color of the three crowns tested; as a result, there is no need for using colored zirconia blanks.

Clinical Significance

Surprisingly, the hue had little-to-no influence on how the crowns turned out. That gives a suggestion for clinicians that there is no longer a requirement to purchase pricey colored blanks. It would be possible to prevent the colored blanks' disadvantage on the binding between the zirconia core and veneer.

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