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Evaluation of color change in CAD-On restorations using different core/veneer thickness ratios and different veneer translucencies

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A R T I C L E I N F O

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A B S T R A C T

Statement of problem: The introduction of partially stabilized zirconium dioxide to the dental field created a path for development of new designs and applications, but still, a minimum framework thickness of 0.5 mm with the remaining thickness of the restoration used for building the ceramic veneer was always recommended. This might have possibly affected the final shade of the restorartion due to the whitish color of Y-TZP.

Purpose: This in vitro study was designed to evaluate the color reproduction ability of CAD-veneered zirconia restorations through the effect of different core-veneer thickness ratios and different translucencies of the Cad-on veneering material.

Methods: Sixty CAD-On restorations were constructed and classified into 3 groups ($n = 20$) of different core/veneer thickness ratios (0.5:1 mm, 0.7:0.8 mm, 1:0.5 mm). Each group was subdivided into 2 subgroups ($n = 10$) according to the CAD-On veneer translucency (High Translucency HT, Low Translucency LT). Cad-On restorations were constructed using the CEREC InLab CAD/CAM System. Color change (ΔE) between groups of the CAD-On restorations was measured using Vita EasyShade Compact. All data was statistically analyzed and presented as mean and standard deviation values. Repeated measurements of data were analyzed with analysis of variance (ANOVA) for significant differences.

Results: There was significant difference ($P < 0.05$) for varrying the core/veneer thickness ratio over (ΔE) while both the veneer translucency and interaction between the core/veneer thickness ratio and veneer transluency had no significant effect.

Conclusion: There was a visually perceptible color change for all core/veneer thickness ratios and all veneer translucencies, but they were all in the clinically acceptable range.

1. Introduction

In the last thirty years there was dramatical increase in patients' demands for superior esthetics and naturally appearing restorations. The demand to achieve a naturally looking restoration is one of the most challenging aspects in dentistry [1].

Some consider the art of achieving an all-ceramic retoration that matches perfectly with the adjacent teeth as being artistic more than scientific. It results from the interplay between two important optical factors: on one hand, the masking capacity of ceramics to block the background color with sufficient material thickness, and on the other hand, the amount of translucency of the ceramic that will allow the natural background color of the tooth to shine through a translucent material and exhibit the most natural appearance. That was proved previously when ***Wahba MM et al*** [2] showed that translucency of the veneering ceramic material greatly affects the transluency and hence the overall appearance of the final restoration.

In addition to the masking capability of the ceramic material and its translucency, several other factors control the success of an esthetic restoration, among which are the individual's perception of color, the light source used for color evaluation, the surface and structural characteristics of both the tooth and the restorative materials used and knowledge of some basic principles of color perception [1].

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Owing to the recent advances in materials technology, evolutionary treatment methods and the advances in computer aided design (CAD) and computer aided manufacturing (CAM) technologies; the high-strength ceramic systems have become increasingly popular. Zirconia, specifically yttria-containing tetragonal zirconia polycrystal (Y-TZP), with unsurpassed mechanical properties, has had its clinical applications expanded from single crowns and short-span FDPs to multi-unit and full arch zirconia frameworks. As zirconia is relatively opaque and monochromatic in color, a layer of veneering ceramic is built on it to provide the restoration with the required esthetics [3] and [4].

However, multiple studies showed that thickness and combination of ceramic layers such as the core, veneer and other speciality ceramic materials have been shown to control the appearance of the ceramic materials and hence the color of the final core-veneered restoration [5–7]. In previous work, ***Bachhav V et al in 2011*** [8], studied the effect of veneering 1 mm thick disc-shaped cores of Lava all-ceramic system (3M ESPE Dental Products) with different thicknesses of dentin veneering ceramic. It was shown that mean ΔE value increased as the dentin ceramic thickness increased with all L*, a* and b* being affected by the change in the dentin ceramic thickness. In a different study, ***Shoukry T et al in 2006*** [7] evaluated the effect of core and veneer thicknesses on the color parameters of two all-ceramic systems and concluded that; ΔE values increase with the total thickness of the ceramic material and that the core/veneer interaction exerted significant influence on both a* and b* values of the final core-veneeerd restoration.

Since the ceramic layer thickness is important for shade development, the utmost precision and control are required for a predictable and reproducible result. However, it's difficult to achieve consistency in layering the various porcelain shades with a free-hand technique which was proved by ***Xiao P et al*** [9] in their study. With the continuous innovations in the field of digital dentistry, CAD/CAM alternative was offered to lessen the variability of color reproduction in the fabrication of ceramic restorations. A procedure-involving CAD/CAM fabrication of both high-strength zirconia coping and a corresponding veneering cap was developed where both parts are sintered together leading to increased mechanical strength of the restoration compared to traditional techniques [10]. This increase in mechanical properties was reported by ***Basso GR et al*** [11] who showed that CAD-on technique reduced the rate of veneer chipping. Also ***Kanat B et al*** [12] showed higher fracture resistance, flexural strength and biaxial flexural strength values for crowns fabricated using CAD-on techniqe when compared to those fabricated from zirconia and veneered with either overpressing or manual layering. This CAD-On veneering technique allows maximum control over the thickness ratio between the core and the veneer as well as allowing the use of high quality material with a minimum of flaws compared to the manual procedures of veneering or heat pressing all of which is required for optimum color match [13].

2. Statement of the problem

The introduction of partially stabilized zirconium dioxide to the dental field created a path for thr development of new designs and applications, but still, a minimum framework thickness of 0.5 mm with the remaining thickness of the restoration used for building the ceramic veneer was always recommended. This might have possibly affected the final shade of the restorartion due to the whitish color of Y-TZP.

Accordingly, this study was designed to evaluate the color reproduction ability of CAD-veneered zirconia restorations through the effect of different core-veneer thickness ratios and different translucencies of the Cad-on veneering material.

The null hypothesis was that changing both the core/veneer thickness ratio and veneer translucency would affect the color change between the groups.

3. Materials and methods

A stainless steel die was machined to simulate an all-ceramic molar crown preparation with 1.5 mm rounded shoulder finish line around the circumference, 7° occlusal convergence, and flat occlusal surface. Sixty zirconia copings were constructed over the master die from InCoris ZI for InLab blocks.[1] They were designed in the software and milled to high precision in the milling unit, using CEREC Inlab[2] system, with different thicknesses; 0.5 mm (n = 20), 0.7 mm (n = 20) and 1 mm (n = 20) (Table 1). After completion of the milling process, complete sintering of the zirconia copings was carried out in high-temperature furnace Infire HTC.[3] Different coping thicknesses were verified using an electronic digital caliper following sintering and before the veneering process.

IPS e.max CAD[4] blocks of different translucencies-HT and LT-were used for construction of the veneering caps using InLab CAD/CAM System, where the sintered zirconia copings were placed over the prepared stainless steel die and scanned. Restorations were then designed according to different thicknesses that were pre-set in the CAD/CAM software to create the IPS e.max CAD veneers with three different thicknesses; 1 mm (n = 20), 0.8 mm (n = 20) and 0.5 mm (n = 20) (Table 1). After the milling process was completed, the thickness of each veneering cap was checked using an electronic digital caliper and its fitness was checked over the corresponding zirconia coping.

For construction of the CAD-on restoration samples, every part of the restoration was designed separately instead of using the "multi-layer" design technique of the software. This method was chosen because the "multi-layer" design technique produces only restorations in an anatomical form while for accurate measurement of color parameters, flat-surface samples with standard thickness were needed.

During the step of designing the veneering cap, a joining gap for the low-fusing glass ceramic applied for the fusion of the coping and veneer, was adjusted through setting the spacer parameter in the InLab software.

Homogenous bond between both the InCoris ZI copings and the IPS e.max CAD was achieved through specially developed fusion glass-ceramic (IPS e.max CAD Crystall./Connect[5]). Part of IPS e.max Crystall./Connect was placed on the occlusal aspect of the zirconia coping and another part was placed in the inner aspect of the IPS e.max CAD veneering structure. The InCoris coping was inserted in

Table 1
Sample grouping.

Core/veneer Thickness Ratio	Group A 0.5:1 mm		Group B 0.7:0.8 mm		Group C 1:0.5 mm	
Translucency	HT n = 10	LT n = 10	HT n = 10	LT n = 10	HT n = 10	LT n = 10
Total						60

[1] Sirona Dental Systems (SDS), Bensheim, Germany.
[2] Sirona, Bensheim,Germany.
[3] Sirona, Bensheim,Germany.
[4] Ivoclar Vivadent, Schaan, Liechtenstein.
[5] Ivoclar Vivadent, Schaan, Liechtenstein.

Table 2
Multivariate test results based on repeated measures ANOVA showing the effect of core/veneer thickness ratio, veneer translucency and interaction between them over L*, a*, b*.

Source	Dependent Variable	Type III Sum of Squares	Mean Square	F	Sig.
Core/veneer Thickness Ratio	L*	26.476	13.238	14.414	0.000[a]
	a*	0.31	0.155	0.98	0.382
	b*	217.772	108.886	95.165	0.000[a]
Translucency	L*	0.081	0.081	0.088	0.768
	a*	23.814	23.814	150.369	0.000[a]
	b*	209.814	209.814	183.374	0.000[a]
Core/veneer Thickness Ratio * Translucency	L*	4.241	2.121	2.309	0.109
	a*	0.291	0.145	0.919	0.405
	b*	5.701	2.851	2.491	0.092

[a] Indicates significant value.

the correct position into the veneering cap and the occlusal aspect of the restoration was held against the vibrating plate of the Ivomix.[6]

During the fusion cycle, crystallization of IPS e.max CAD was completed.

After completion of the firing cycle, specimens were allowed to cool and then each specimen was measured against a white die where the CIE L*a*b* values were calculated using Vita EasyShade Compact[7] that was caliberated before each group measurement inorder to standardize the reproducibility. Color difference between different groups was then calculated according to the following equation;

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

4. Statistical analysis

Data was presented as mean and standard deviation (SD) values. All the data was collected and tabulated. Statistical analysis was performed by Microsoft Office 2010 (Excel) and Statistical Package for Social Science (SPSS) version 20.

2-way ANOVA and 1-way ANOVA were used to assess effect of Core/veneer thickness ratio, veneer translucency and interaction between them overΔE. Simple main effect pair wise comparison was used to delineate significance between groups if ANOVA test was significant.

5. Results

5.1. Effect of core/veneer thickness ratio and veneer translucency over L*, a*, b values

Multivariate test showed that there was significant difference ($P < 0.05$) for the effect of core/veneer thickness ratio over L* and b* values, but not over the a* value. Veneer translucency showed a significant difference over the a* and b* values, but not over the L* value while the interaction between both the core/veneer thickness ratio and veneer translucency had no significant difference over any of the three values (Table 2).

The above data showed that with increasing the veneer thickness from group C to group A, L* value decreased with significant difference between group A and group C and group A and B ($P < 0.05$). a* value didn't significantly change between the groups and stayed in the red region showing the highest value in group C and the lowest value in group B while b* value decreased with significance difference between the three groups being highest in group C and lowest in group A (Table 3).

The above data showed that changing the veneer translucency between either HT or LT didn't significantly affect the L* value of the specimens, but with showing lower value in the HT group. There was significant difference ($P < 0.05$) for the a*and b* values between the HT and LT groups where more reddish and yellowish values where shown for the LT group (Table 4).

5.2. Effect of core/veneer thickness ratio and veneer translucency over ΔE

According to the given results, it was shown that ΔE values were visually perceptible ΔE>2.6 for all core/veneer thickness ratios yet where still clinically acceptable ΔE<5.5 (Table 5).

1-way ANOVA showed no significant difference in different core/veneer thickness ratios over delta E, but with the highest value being in group A and the lowest in group C (Table 6).

ΔE values between different core/veneer thickness ratios were found to be visually perceptible for both the HT and LT groups being higher for all LT groups of different thicknesses (Table 7).

Table 3
Pairwise comparison showing the effect of core/veneer thickness ratio over L*, a* and b* values.

CIELab Value	Core/veneer Thickness Ratio	Mean	Std. deviation
L*	Group A	87.9600[b]	1.08210
	Group B	89.2400[a]	0.65556
	Group C	89.4700[a]	2.45847
a*	Group A	0.2650[a]	1.16276
	Group B	0.1950[a]	0.78571
	Group C	0.3700[a]	2.11866
b*	Group A	23.7250[c]	0.56111
	Group B	25.2650[b]	0.81956
	Group C	28.3100[a]	2.01544
	Group C	28.3100[a]	2.01544

Similar superscripts indicate non-significant.

Table 4
Pairwise comparison showing the effect of veneer translucency over L*, a* and b* values.

CIELab Value	Veneer Translucency	Mean	Std. deviation
L*	HT	88.85[a]	1.169
	LT	88.9267[a]	1.18
a*	HT	−0.3533[b]	0.4576
	LT	0.9067[a]	0.3258
b*	HT	23.896[b]	2.49
	LT	27.6367[a]	1.903

Similar superscripts indicate non-significant.

[6] Ivoclar Vivadent, Schaan, Liechtenstein.
[7] Vita Zahnfabrik. Rauter GmbH & Co.KG.

Table 5
Mean (SD) ΔE between different veneer translucencies in different core/veneer thickness ratio.

	N	Mean	Std. Deviation
Group A	10	4.9222	1.36862
Group B	10	4.2352	1.36735
Group C	10	3.5914	1.89209
Total	30	4.2496	1.60564

2-way ANOVA showed significant difference ($P < 0.05$) of varying the core/veneer thickness ratio over ΔE while both veneer translucency and interaction between core/veneer thickness ratio and veneer translucency had no significant effect (Table 8).

Data showed significant difference ($P < 0.05$) in ΔE values between group A vs. group B and group C vs. group A, also between group B vs. group C and group C vs. group A in which it showed the highest value with the lowest value being between group A vs. group B (Tables 9–11).

6. Discussion

The present study aimed at investigating the effect core-veneer thickness ratio as well as the effect of the veneer translucency on the color change of CAD-veneered Y-TZP restorations.

A white die was used in the current study, with reference to some previous researches [14] and [15], for the purpose of color measurement in order to eliminate the influence of the background on the measured color. In other previous studies, neutral grey background had been used [7] and [9].

Color measurement was done using Vita EasyShade Compact spectrophotometer whose CIELab output is based on D65 illuminant and 2-degree standard observer [8]. CIELab measurements make it possible to evaluate the amount of perceptible color change in each specimen. It's a uniform 3-dimensional color order system. The L^*coordinate represents the lightness-darkness of the specimen where the greater the L^*, the lighter the specimen is. The a^* coordinate expresses the chroma along the red-green axis where a positive a^* relates to the amount of redness and a negative a^* relates to the amount of greenness of the specimen. The b^*coordinate measures chroma along the yellow-blue axis where a positive b^* relates to the amount of yellowness while a negative b^* relates to the amount of blueness of the specimen.

Table 6
1-way ANOVA showing the effect of different core/veneer thickness ratios over ΔE.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8.859	2	4.429	1.815	0.182
Within Groups	65.905	27	2.441		
Total	74.764	29			

Table 7
Mean (SD) ΔE between different core/veneer thickness ratios in different veneer translucencies.

	Translucency	N	Mean	Std. Deviation
Group A vs. Group B	HT	10	2.62	1.31555
	LT	10	2.78	0.80581
Group B vs. Group C	HT	10	2.9	0.70087
	LT	10	3.7	0.39665
Group C vs. Group A	HT	10	4.46	1.54564
	LT	10	5.65	1.59318

Table 9
Mean (SD) ΔE for different veneer translucencies.

Veneer Translucency	Mean	Std. deviation
HT	3.329	1.5
LT	4.068	2

Table 10
Pairwise comparison showing the effect of core/veneer thickness ratio over ΔE.

Core/Veneer Thickness Ratio	Mean	Std. deviation
Group A vs. Group B	2.701[b]	1.1
Group B vs. Group C	3.337[b]	1.5
Group C vs. Group A	5.058[a]	1.9

Similar superscript indicate non-significant.

Table 11
Mean (SD) ΔE for the effect of interaction between core/veneer thickness ratio and veneer translucency.

	Veneer Translucency	Mean	Std. Deviation
Group A vs. Group B	HT	2.62	1.31555
	LT	2.78	0.80581
Group B vs. Group C	HT	2.9	0.70087
	LT	3.7	0.39665
Group C vs. Group A	HT	4.46	1.54564
	LT	5.65	1.59318

Total color difference is calculated according to the equation; $\Delta E = ((\Delta L^*)2 + (\Delta a^*)2 + (\Delta b^*)^2)^{1/2}$ [16]. Because the human eye has a limited capacity to recognize small differences in color and the interpretation of visual color comparisons is subjective, the threshold level for visually perceivable or clinically acceptable color differences varies based on individual report.

Based on in vitro conditions, ***Douglas RD et al*** [17] stated that the threshold for an acceptable color difference between metal ceramic crowns was reported to be 1.7 ΔEab units while in another study based on composite resin specimens, 3.3 ΔEab units was considered an acceptable threshold [18]. As a clinical perceptible threshold, ΔEab value of 3.7 units was judged as a perfect match based on composite resin veneer restorations and their comparison teeth [5]. Based on a recent clinical study, it was reported that the perceivable color difference for 50% of the dentists was ΔEab 2.6 while that at which 50% of the dentists would go for remake of the restoration due to color mismatch was 5.5 units [19], a guidance which we followed in the current study.

In the present study, ΔEab between different veneer translucencies as well as between different core veneer/thickness ratios was always found to be visually perceptible, but clinically acceptable where $2.6 < \Delta Eab < 5.5$.

Table 8
2-way ANOVA showing the effect of core/veneer thickness ratio, veneer translucency and interaction between them over ΔE.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Veneer Translucency	8.186	1	8.186	3.635	0.062
Core/veneer Thickness Ratio	59.491	2	29.746	13.208	0.000[a]
Veneer Translucency * Core/veneer Thickness Ratio	2.779	2	1.390	0.617	0.543

[a] Indicates significant value.

The null hypothesis for the present study was partially accepted where it was shown that when ΔEab was measured between different veneer translucencies in groups of different core/veneer thickness ratios, it was found that as the veneer thickness decreased, the amount of color change decreased where it had the highest value in group A and was least in group C. This could be related to the fact that the core had the dominant effect in producing color change in small veneer thicknesses, while in high veneer thickness ratios, the veneer had the dominant effect and thus the difference between HT and LT groups was obvious.

It was also shown here that ΔEab changed between different core/veneer thickness ratio groups in both HT and LT with the greatest color difference being between group A and C and the least between group A and B.

Groups of the low veneer translucency always showed a higher color change than those of the high veneer translucency of the corresponding thickness ratio. This could be attributed to the masking effect of the low translucency veneer.

These findings were found in agreement with previous research where ***Bachhav V et al*** [8] stated that mean ΔE value increased as the dentin ceramic thickness for zirconium based all-ceramic specimens increased. ***Son HJ et al*** [20] concluded in a study that porcelain thickness of Lava ceramics had less influence on restoration color change when compared to IPS ceramics. In a study conducted by ***Shoukry T et al*** [7] experimenting the effect of core and veneer thicknesses on the color parameters of IPS Empress and In-Ceram Spinell, they concluded that there was a difference in the influence by the core and veneer thickness. They showed that total disc thickness had significant effect over final color appearance of Spinell ceramics, but also stated that it wasn't likely that altering the ratio of core/veneer thickness could effectively reduce ΔE values for Spinell ceramics. Conversely, in the current study, it was proved that there was significant difference in ΔE values when varying the core/veneer thickness ratio.

Regarding L^*, a^* and b^* values of the CIELab system, results of the current study showed that changing the core/veneer thickness ratio caused a change in all 3 coordinates of color that was significant over both L^* and b^*, but insignificant over a^*. There was also a significant effect for changing the veneer translucency over a^* and b^* coordinates, but not over L^* coordinate.

L^* that reflects lightness and darkness of the restoration was found to decrease with increasing the veneer thickness where it showed the lowest value for group A and increased towards group C. This reflected a decrease in the lightness of the restoration as the veneer thickness increases on expense of the core thickness. This could be explained by the decreased light being reflected from the zirconia core with increasing the veneer thickness due to diffuse reflection and scattering of light in both the zirconia, the veneering ceramic and the interface between them.

This finding is well-documented in literature where ***Bachhav V et al*** [8] showed that layered ceramic influenced the final shade partially due to translucency since thicker discs were less translucent. ***Jalili H et al*** [21] tested the effect of ceramic thickness on the color of all ceramic restoration fabricated of lithium disilicate based glass ceramic and veneered with a specific fluoroapatetite containing glass-ceramic. They stated that L^* value decreased as the total thickness of the specimens increased and explained this by the increased absorption of incident light in thicker ceramic layers leading to reduction in the amount of reflected light. Also, ***Uludag B et al*** [22] and ***Son HJ et al*** [20] proved that L^* value decreased as ceramic thickness increased.

Shoukry T et al [7] showed that L^* value was independent of the core and veneer thickness when measured for leucite ceramics, but was significantly affected with core and veneer for Spinell restorations with the core having a greater effect. They attributed this to the fact that Spinell has higher contrast ratio than leucite and thus increasing the core thickness would cause greater light scattering in Spinell than leucite.

Lee YK et al [15] tested the layered color of all-ceramic core and veneer ceramics and stated that L^* value of layered restorations was primarily influenced by the L^* value of the core ceramic.

For a^* and b^* values, it was shown according to the present study that as the veneer thickness decreased, b^* value increased making restorations appear more yellowish in color while a^* value changed between groups and was in the red region. Explaining this could be based on the increased effect of the core when the veneer thickness decreased.

Opposing to our findings, authors in some previous studies showed that increasing the veneer thickness, caused restorations to become more yellowish [8,20–22].

Moreover, ***Son HJ et al*** [20] showed that the greatest changes in b^* value occurred when dentin thickness was thin where thickness-dependant reflectance changes were found to be significantly greater at shorter wavelengths than at longer wavelengths.

Also, ***Uludag B et al*** [22] stated that In-Ceram specimens appeared redder and more yellowish in color with the increase in dentin thickness because the effect of diffuse reflection of the core ceramic diminished and the majority of diffuse reflection occurred in the dentin layer.

Changing the veneer translucency also affected the a^* and b^* values significantly where specimens appeared more yellowish and reddish in color when veneered with low translucency veneering material. ***Lee YK et al*** [15] proved that a^* and b^* values of layered restorations where influenced primarily by the a^* and b^* of the veneer. ***Dozic A et al*** [14] in their study testing the influence of porcelain layer thickness on the final shade of ceramic restorations showed that there was a tendency for a^* and b^* values to increase when the thickness of opaque porcelain increased.

Regarding the fact that this study was an in vitro one, specimens were formulated to simulate, as much as possible the clinical conditions in which the restoration would function, but still some limitations were there. All crowns were constructed in a non-anatomical form with flat surfaces in an attempt to standardize the thickness for more controlled color measurement process. Color measurements were carried out on artificial white die and thus eliminating the role of the tooth substrate in the process of color reproduction. Hence, more studies are recommended for further investigation of the effect of abutment and cement color, as well as the effect of different intra-oral conditions on the low temperature degradation on Y-TZP and its effect on the final color of the restoration.

7. Conclusions

- ➢ There was a visually perceptible color change for all core/veneer thickness ratios and all veneer translucencies, but they were all in the clinically acceptable range.
- ➢ Variation in core/veneer thickness ratio caused significant color change whereas veneer translucency had little effect.
- ➢ The highest color change was found between group A and group C when low translucency veneer was used. The lowest color change was found between the high and low translucency groups in group C.
- ➢ Varying the core/veneer thickness ratio had significant effect only over L^* and b^* color parameters, and veneer translucency had significant effect over a^* and b^* parameters while the interaction between both factors showed no significant variance in any of the CIELab color parameters.

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