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Effect of core/veneer thickness ratio and veneer translucency on absolute and relative translucency of CAD-On restorations

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ABSTRACT

Statement of problem: With zirconia being chalky white in color with poor optical properties, several veneering techniques have been adopted to improve the esthetic qualities of zirconia-based restorations. Yet, these techniques didn't recommend the optimum combination of core-veneer thickness ratios and veneer translucency needed to provide the ultimate optical properties.
Purpose This in vitro study was designed to evaluate the translucency of CAD-veneered zirconia restorations through the effect of different core-veneer thickness ratios, and different translucencies of Cad-On veneer 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. Translucency of the CAD-On restorations was measured through 2 methods; relative translucency expressed in terms of contrast ratio (CR) using Vita EasyShade Compact and absolute translucency using Unicam spectrophotometer Helios. 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 ($P < 0.05$) only for the effect of veneer translucency over the contrast ratio values, while with the core/veneer thickness ratio and interaction between veneer translucency and core/veneer thickness ratio had no significant difference over the contrast ratio values. For absolute translucency, there was significant difference ($P < 0.05$) for the effect of core/veneer thickness ratio, veneer translucency and interaction between them.
Conclusions: Only veneer translucency had significant effect over contrast ratio values, while on the other hand, absolute translucency values were significantly affected by the core/veneer thickness ratio, veneer translucency and interaction between them. It was clear that absolute translucency measurements showed higher translucency values for the restorations than contrast ratio measurements.

1. Introduction

Core-veneered restorations are considered the cornerstone for prosthetic dentistry combining both a high strength core and an esthetic veneer. However, strength limitations hindered the use of all ceramic core materials into more than three or four unit fixed partial denture restorations. It was until the introduction of Yttruim tetragonal zirconia polycrystals as core material that opened the road to fabrication of extensive multi-unit restorations with high success rate. The unique chemical stability, the superior mechanical properties, and the esthetic color, combined with CAD/CAM technology all make zirconia the core material of choice [1,2].

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Since Zirconia is relatively opaque and monochromatic in color, it's necessary to build a layer of veneering ceramic on it to provide the restoration with the required esthetics [3]. However, it was stated that when a restoration is composed of different layers with unspecified thicknesses, the final color of the restoration might be unpredictable. In addition to color, a key optical factor that permits a pleasing harmony of a restoration is translucency. Translucency was noted by many authoress as a cornerstone for the esthetic success of ceramic restorations [4,5]. *Heffernan et al* [6,7], stated previously that all-ceramic core materials have a wide range of translucency and that the range of translucency identified in the veneered all ceramic systems they tested may affect their ability to match natural teeth. However, for accurate and consistent color reproduction and for the ability to produce an esthetically integrated restoration, it becomes imperative to understand the optical properties of natural teeth. We must always bear in mind that color and translucency are two highly correlated properties where the apparent color and translucent properties of natural teeth are the result of the reflectance from dentin modified by absorption, scattering and thickness of enamel [8].

A material's translucency could be measured in terms of relative translucency or absolute translucency. Relative translucency is expressed as contrast ratio (CR=Yb/Yw) which is defined as the ratio of the illuminance (Y) of the test material when it's placed over a black background (Yb) to the illuminance of the same material when it's placed over a white background (Yw) [9]. This ratio tends towards unity for opaque materials and towards zero for transparent materials [10]. Absolute translucency, on the other hand, can be measured as percent of diffuse and direct transmitted light (total transmission T%) which is more difficult to measure and necessitates use of dual beam, integrating sphere radiometer or spectrophotometer able to capture all of the light transmitted through a specimen in comparison to the intensity of light from a split beam [11].

Translucency of ceramic materials has been shown to be affected by thickness and combination of ceramic layers such as the core, veneer and other speciality ceramic materials [10,12–14]. *Antonson et al* [13] tested the contrast ratio of veneering and core ceramics and stated that mean translucency increased as thicknesses decreased for different all-ceramic systems. *Heffernan et al* [6,7] suggested that the thickness of the core material can affect its translucency.

Comparing the relative and absolute translucency of dental ceramics using a wide range of dental ceramics in different thicknesses, *Spink L et al in 2009* [15] found out that the relationship between absolute and relative translucency was sensitive up to 50% only where once the translucency of the material dropped below 50%, contrast ratio converged to one. Hence, for ceramic materials that allow light transmission greater than 50%, contrast ratio could be used to rank order translucencies. They also stated that light transmission decreased as the material's thickness increased, but in a material specific manner. In the same study, they also observed that the light transmission through zirconia specimens was least affected by change in thickness and of all structural ceramics, Vita Y-Z zirconia was the least affected by increase in thickness.

On the other hand, *Bldissara et al in 2010* [16] evaluated the translucency of zirconia copings made with different CAD/CAM systems. In that study, translucency measurement through direct transmission of light showed that all zirconia copings allowed light to pass through the material, thus they could be considered as translucent to a certain degree.

Since the ceramic layer thickness is important for shade development, and the utmost precision and control are required for a predictable and reproducible result, different core veneering techniques have been employed with each technique said to be able to improve the esthetic properties of Y-TZP restorations. Yet, each of these veneering techniques, such as manual layering, pressing or double veneer technique has shown to have its own drawbacks [17–19].

A new procedure for veneered all-ceramic crown restorations, using a CAD/CAM-fabricated high-strength zirconia coping and a corresponding CAD/CAM fabricated veneer has been introduced. Parts of the restoration can be sintered together by means of a glass-ceramic powder in one bake. This procedure of sintering core and veneering leads to an increase in mechanical strength, compared to traditional techniques, enabling a lower clinical chipping rate of the veneering material. This was demonstrated in an in-vitro study carried out by *Schmitter M et al* [20] when they reported higher fracture resistance of zirconia crowns constructed and veneered using CAD-on technique compared to those veneered by regular layering technique. Also *Kanat B et al* [21] showed higher fracture resistance, flexural strength and biaxial flexural strength values for crowns fabricated using CAD-on technique when compared to those fabricated from zirconia and veneered with either overpressing or manual layering. Two main reasons might be responsible for the greater strength. First, the lithium-disilicate ceramic used for the veneer cap has a greater flexural strength in comparison to the veneering porcelain used for the layering technique. Second, the CAD/CAM-process uses high quality material with a minimum of flaws compared to the manual procedures of veneering or heat pressing [22]. On the other hand, when either veneer chipping or framework fracture occurred in CAD-on fabricated test specimens, it happened at much greater loads than those of the oral environment which still proved that CAD-on technique reduced the rate of veneer chipping [23].

2. Statement of the problem

With zirconia being chalky white in color with poor optical properties, several veneering techniques have been adopted to improve the esthetic qualities of zirconia-based restorations. Yet, these techniques didn't recommend the optimum combination of core-veneer thickness ratios and veneer translucency needed to provide the ultimate optical properties.

Accordingly, this study was designed to evaluate the translucency of CAD-veneered zirconia restorations through the effect of Core-Veneer thickness ratio (0.5 mm/1 mm, 0.7 mm/0.8 mm and 1 mm/0.5 mm), as well as the translucency of CAD-on veneer material (High Translucency, and Low Translucency). The null hypothesis was that neither the change in the core/veneer thickness ratio nor the translucency of the veneer would affect the relative or absolute translucency of CAD-veneered restorations.

3. Materials and methods

Sixty CAD-on restorations were constructed and classified into 3 groups (n = 20) of different core/veneer thickness ratios (Group A 0.5:1 mm, Group B 0.7:0.8 mm, Group C 1:0.5 mm). Each group was subdivided into 2 sub-groups (n = 10) according to the CAD-On veneer translucency (High Translucency HT, Low Translucency LT) (Table 1).

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

A stainless die was constructed to represent the master die for molar preparation (Fig. 1). Instead of using the "multi-layer" design technique of the software for construction of the CAD-on restoration samples, every part of the restoration was designed separately. This was done because the "multi-layer" design technique produces only restorations in an anatomical form while in this study flat-surface samples with standard thickness were needed to allow accurate measurement of translucency.

First, zirconia copings were constructed over the master stainless steel 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. After milling, zirconia copings were sintered in high-temperature furnace Infire HTC.[3] Following sintering and before the veneering process, the different coping thicknesses were checked using an electronic digital caliper. Zirconia copings were then placed on the prepared stainless steel die and scanned for the construction of the veneering caps. The veneering caps were milled out of IPS e. max CAD[4] of different translucencies, and with different thicknesses that were pre-set in the CAD/CAM software. After the milling process was completed, the thickness of each veneering cap was checked using an electronic digital caliper and its fit was checked over the corresponding zirconia coping.

A joining gap for the fusing glass ceramic used for fusion of the coping and veneer together was created through setting the spacer parameter in the InLab software during the step of designing the veneering cap. Homogenous fusion between both the InCoris ZI framework and the IPS e. max CAD took place through specially developed fusion glass-ceramic (IPS e. max CAD Crystall./Connect[5]). Some IPS e. max Crystall./Connect was placed on the occlusal aspect of the zirconia coping and another small amount of the IPS e. max Crystall./Connect was placed in the inner aspect of the IPS e. max CAD veneering structure. The InCoris framework was inserted in the correct position into the veneering structure and the occlusal aspect of the restoration was held against the vibrating plate of the Ivomix.[6]

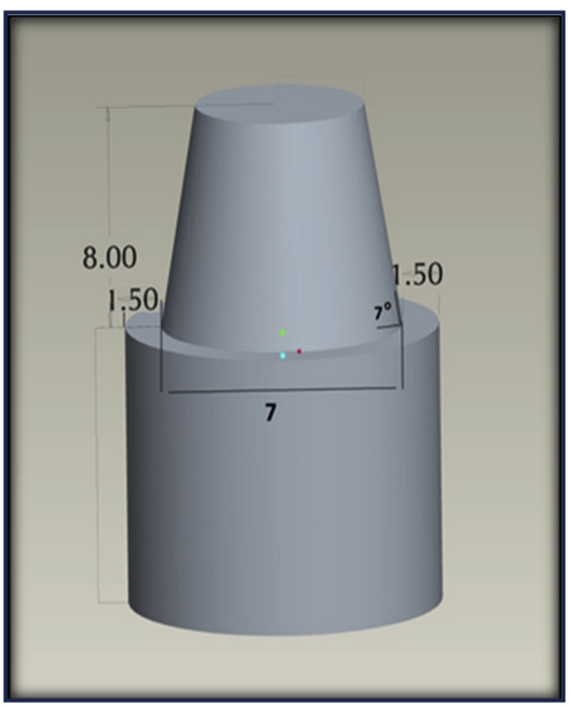

Fig. 1. Diagramatic drawing for Stainless steel die.

A slight pressure was applied against the Incoris framework so that the IPS e. max Crystall./Connect is evenly squeezed out of the entire circular fusion joint indicating a proper joint with sufficient amount of material (Fig. 2) The crystallization of the IPS e. max CAD material took place during the same firing cycle of IPS e. max Crystall./Connect.

After completion of the firing cycle, specimens were allowed to cool and then each specimen was measured against both black and white dies where in each time the CIE L* value was calculated using Vita EasyShade Compact that was calibrated before each group measurement inorder to standardize the reproducibility.

Contrast ratio of each sample was calculated according to the following equation;

$$CR = L_b/L_w$$

where; CR is the contrast ratio.L_b is the lightness measured over a black background.L_w is the lightness measured over a white background.

Unicam spectrophotometer Helios[7] was used to measure the light transmittance % through the restorations. It's an UV- Visible spectrophotometer designed for research work. It operates by emitting a light beam that passes through a sample placed in a special cuvete and then measuring the intensity of light reaching the detector (Fig. 3).

A special holder was constructed to hold the restoration samples. A plastic holder having the same dimensions as the device cuvete was made. Two holes corresponding to the occlusal and cervical surfaces of the samples were made in the especially designed holder. The holder was painted in black to ensure that light beam passed only through the samples.

Fig. 2. Vibration of the CAD-on restoration using Ivomix.

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.
6 Ivoclar Vivadent, Schaan, Liechtenstein.
7 Spectronic Unicam, Cambridge, UK.

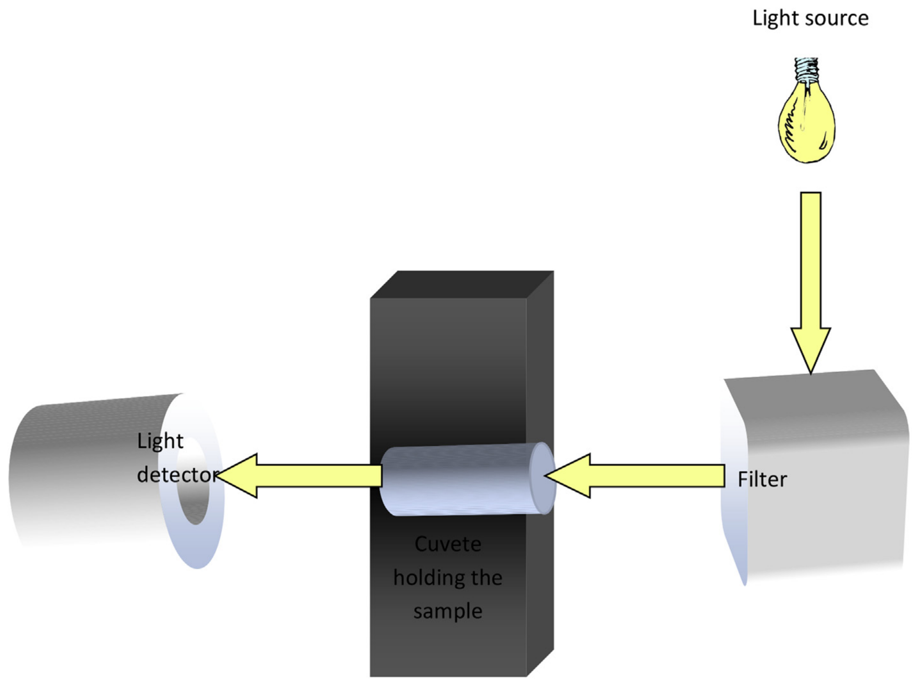

Fig. 3. Diagramatic drawing for Unicam Helios Spectrophotometer.

Before each sample measurement, light intensity passing through a blank (air) ($I_\circ$) was measured. Each sample was placed in the especially designed holder and placed in the spectrophotometer cell in such a way that light beam passed through it in a cervico-occlusal direction.

Light intensity (I) reaching the detector was calculated and for each sample transmittance percentage was calculated where; $T = I/I_\circ$

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 was used to assess effect of Core/veneer thickness ratio and veneer translucency over absolute translucency and contrast ratio. Simple main effect pair wise comparison was used to delineate significance between groups if 2-way ANOVA was significant.

5. Results

5.1. Contrast ratio measurements

The 2-way ANOVA test showed significant difference ($P < 0.05$) for the effect of veneer translucency over the contrast ratio values, but with the core/veneer thickness ratio and interaction between veneer translucency and core/veneer thickness ratio having no significant difference over the contrast ratio values (see Tables 2 and 3).

5.2. Absolute translucency measurements

2-way ANOVA test showed significant difference ($P < 0.05$) for the effect of core/veneer thickness ratio, veneer translucency and interaction between them over absolute translucency of the test specimens (see Tables 4 and 5).

It was shown that there was significant difference ($P < 0.05$) in absolute translucency for all core/veneer thickness ratios being highest in group A and lowest in group C (see Table 6).

It was shown that there was significant difference in absolute

Table 2
Mean (SD) contrast ratios of different core/veneer thickness ratios and different veneer translucencies.

Descriptive Statistics				
Core/veneer Thickness Ratio	Veneer Translucency	Mean	Std. Deviation	N
Group A	HT	0.9501	0.02059	10
	LT	0.9713	0.00952	10
	Total	0.9607	0.01904	20
Group B	HT	0.9583	0.01867	10
	LT	0.9676	0.01146	10
	Total	0.9629	0.01582	20
Group C	HT	0.9581	0.00791	10
	LT	0.9665	0.01041	10
	Total	0.9623	0.00997	20
Total	HT	0.9555	0.01656	30
	LT	0.9685	0.01034	30

Table 3
2-way ANOVA test showing the effect of core/veneer thickness ratio, veneer translucency and interaction between them over contrast ratio.

	Type III Sum of Squares	df	Mean Square	F	Sig.
Core/veneer Thickness Ratio	5.148E-005	2	2.574E-005	0.133	0.876
Veneer Translucency	0.003	1	0.003	13.016	0.001[a]
Core/veneer Thickness Ratio *Veneer Translucency	0.001	2	0.000	1.316	0.277

[a] indicates significant value.

translucency between both HT and LT groups ($P < 0.05$) with the HT group showing higher translucency values (see Table 7).

There was significant difference ($P < 0.05$) in absolute translucency between the HT and LT groups in both groups A and C while there was no significant difference between the two veneer translucencies in group B (see Table 8).

6. Discussion

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

In the current study, both relative and absolute translucencies where measured for the test specimens. Relative translucency was measured through the ratio between the L* value of each specimen when placed against black and white dies using the Vita EasyShade Compact where contrast ratio (CR) is one of the most widely used methods to compare relative translucency. It's measured by the ratio of the reflectance from an object resting on a black backing to the reflectance obtained for the same material against a white backing where $CR = L^*_b/L^*_w$ [6,7,13,15]. As CR decreases, translucency of the material increases [9].

On the other hand, testing for absolute translucency was done using Unicam Helios Spectrophotometer to calculate percentage of light transmission.

In the current study, the null hypothesis was rejected for the effect of changing the veneer translucency on relative translucency where results showed significant difference in contrast ratio values between specimens veneered using high translucency veneering material and those veneered using low translucency veneer where the low translucency groups showed higher contrast ratio levels.

Both core/veneer thickness ratio and interaction between core/veneer thickness ratio and veneer translucency had no significant effect on contrast ratio levels. The insignificant effect of varrying the core/veneer thickness ratio was in accordance with previous research that stated that, as translucency of a material drops below 50%, contrast ratios converge to one [15]. In the current study, all contrast ratio levels ranged from 0.95 to 0.97 which is approximating to 1. Also, *Antonson S and Anusavice K* [13] proved that for Procera All-Ceram, which was the least translucent core material used in their study, changing the core thickness from 0.7 mm to

Table 4
Mean (SD) absolute translucency values for different core/veneer thickness ratios and different veneer translucencies.

Core/veneer Thickness Ratio	Veneer Translucency	Mean	Std. Deviation
Group A	HT	29.9636	13.84654
	LT	26.1712	13.54097
	Total	28.0674	13.82111
Group B	HT	27.1963	13.27903
	LT	26.2488	13.66948
	Total	26.7225	13.47980
Group C	HT	25.7493	13.57763
	LT	23.5800	13.03484
	Total	24.6647	13.34901
Total	HT	27.6364	13.67634
	LT	25.3333	13.46955
	Total	26.4849	13.62070

Table 6
Pairwise comparison showing the effect of different core/veneer thickness ratios on absolute translucency.

Core/veneer Thickness Ratio	Mean	Std. deviation
Group A	28[a]	13.8
Group B	26.7[b]	13.4
Group C	24.66[c]	13.34

Different superscripts (a,b,c) indicate significance.

Table 7
Pairwise comparison showing the effect of different veneer translucencies over absolute translucency.

Veneer Translucency	Mean	Std. deviation
HT	27.6[a]	13.6
LT	25.33[b]	13.5

Different superscript indicate significance.

Table 8
Pairwise comparison showing the effect of interaction between different core/veneer thickness ratios and different veneer translucencies over absolute translucency.

Core/veneer Thickness Ratio	Veneer Translucency	Mean	Std. Deviation
Group A	HT	29.90[a]	13.852
	LT	26.11[b]	13.548
Group B	HT	27.13[a]	13.280
	LT	26.17[a]	13.663
Group C	HT	25.75[a]	13.578
	LT	23.58[b]	13.035

Similar superscript indicate non-significance.

Table 5
2-way ANOVA test for the effect of core/veneer thickness ratio, veneer translucency and interaction between them over absolute translucency.

Tests of Between-Subjects Effects					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Core/veneer Thickness Ratio	9421.978	2	4710.989	25.872	0.000[a]
Veneer Translucency	6380.671	1	6380.671	35.042	0.000[a]
Core/veneer Thickness Ratio *Veneer Translucency	1633.497	2	816.749	4.485	0.011[a]

[a] indicates significant value.

1.5 mm caused only 16% decrease in relative translucency. That led to the conclusion that the translucency effect on esthetics for the least translucent ceramic wouldn't be significantly affected by variation in thickness.

On the other hand and regarding absolute translucency measurements, the null hypothesis was rejected where results showed significant difference in absolute translucency values with changing core/veneer thickness ratio, veneer translucency and with the interaction between both of them. Increasing the core thickness caused a decrease in transmission percentage of light and lower absolute translucency values where group A had the highest absolute translucency level while group C was the least. It was also evident that high translucency groups always showed higher values of absolute translucency than low translucency groups among all thickness ratio groups. Those results were coincident with what was stated in a previous study when *Joeng I et al* [24] showed that changing the thickness and type of the veneering ceramic had a major effect on absolute translucency of bilayered zirconia restorations veneered with pressable ceramics. It was probably the higher transmission of light through the high translucency veneer compared to the low translucency one that caused the higher translucency levels for the HT groups in our study. On the other hand and regarding the core thickness, it was clear that decreasing the core thickness caused increase in the absolute translucency values. This could be attributed to the high opacity of zirconia which caused decrease in direct transmission of light as its thickness increased. This was also proved by *Spink L et al* [15] that showed a drop in direct transmission percentage from 68.99% to 67.88% when thickness of Vita Y-Z zirconia increased from 0.3 to 0.5 mm. They stated that as the thickness increased, light had to travel further within the material and hence, light would be subjected to increased absorption and scattering and decreased transmission. Results were also matching with what was observed by *Kim H et al* [25] when they noticed increase in translucency of zirconia ceramics with increasing thickness reduction.

Results of present study came coincident with what was proved by *Spink L et al* [15] who stated that sensitivity of direct transmission was higher than that of contrast ratio measurements where contrast ratio measures diffuse reflectance from a specimen. Contrast ratio wouldn't have the ability to detect small changes in light transmission if a material has a high absorbance coefficient or high scattering coefficient. They claimed that absolute translucency measured through percent transmission should be the gold standard for measuring translucency of dental ceramics.

According to the above discussed results, it's recommended that for optimum translucency, CAD-veneered restorations should be made using high translucency veneering material in 0.5:1 mm core to veneer ratio. However, 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. Translucency measurements were carried out on artificial white and black dies and thus eliminating the role of the tooth substrate.

7. Conclusions

- Veneer translucency had significant effect over contrast ratio values where the low translucency groups showed higher values.
- Absolute translucency was significantly affected by the core/veneer thickness ratio, veneer translucency and interaction between them where the highest transmission percentage was recorded for group A (0.5/1 mm) using high translucency veneer.
- Absolute translucency measurements showed higher translucency values for the restorations than contrast ratio measurements.

8. Recommendations

The authors recommend more studies for further investigation of the effect of abutment substrate color, cement color and thickness and other intra-oral conditions when the restorations are produced in a fully-anatomical form.

Also, further investigations regarding the effect of different core/veneer thickness ratios and veneer translucency on the color of CAD-on restorations.

References

[1] Sundh A, Molin M, Sjogren G. Fracture resistance of Yttrium oxide partially-stabilized zirconia all-ceramic bridges after veneering and mechanical fatigue testing. Dent Mater 2005;21:476–82.
[2] Ardlin BI. Transformation-toughened zirconia for dental inlays, crowns and bridges: chemical stability and effect of low-temperature aging on flexural strength and surface structure. Dent Mater 2002;18:590–5.
[3] Denry I. Ceramics for dental applications: a review. Materials 2010;3:351–68.
[4] Lee YK, Cha HS, Ahn JS. Layered color of all- ceramic core and veneer ceramics. J Prosthet Dent 2007;97:279–86.
[5] Michalakis KX. Light transmission of post and cores used for the anterior esthetic region. Int J Periodontics Restor Dent 2004;24:462–9.
[6] Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucency of six all-ceramic systems. Part I: core materials. J Prosthet Dent 2002;88:4–9.
[7] Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucency of six all-ceramic systems. Part II: core and veneer materials. J Prosthet Dent 2002;88:10–5.
[8] Seghi RR, Johnston W, O'Brien W. Spectrophotometric analysis of color differences between porcelain systems. J Prosthet Dent 1986;56:35–40.
[9] Hunter RS, Harold RW. The measurement of appearance. second ed. New York: John Wiley and Sons; 1987. p. 162–93.
[10] Kingery W, Bowen D. Introduction to ceramics. second ed. New York: John Wiley and Sons; 1976. p. 646–89.
[11] Brodbelt RW, O'brien WJ, Fan PL. Translucency of dental porcelains. J Dent Res 1980;59(1):70–5.
[12] Jonston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. J Dent Res 1989;68:819–22.
[13] Antonson SA, Anusavice KJ. Contrast ratio of veneering and core ceramics as a function of thickness. Int J Prosthodont 2001;14:316–20.
[14] Xiao P, Lei Z. Effect of veneering techniques on color and translucency of Y-TZP. J Prosth 2010;19:465–70.
[15] Spink L, Robert K, Douglas A, John A, Patchanee R. A comparison of absolute translucency and relative translucency of dental ceramics. University of Connecticut; 2009.
[16] Baldissara P, Altin L, Leonardo C, Felipe L, Roberto S. Translucency of zirconia copings made with different CAD/CAM systems. J. Prosth. Dent 2010;104: 6–12.
[17] Aboushelib MN, de Jager N, Kleverlaan CJ. Microtensile bond strength of different components of core veneered all-ceramic restorations. Dent Mater 2005;21:984–91.
[18] Aboushelib MN, Kleverlaan CJ, Feilzer AJ. Microtensile bond strength of different components of core veneered all-ceramic restorations. Part II: zirconia veneering ceramics. Dent Mater 2006;22:857–63.
[19] Aboushelib MN, Kleverlaan CJ, Feilzer AJ. Microtensile bond strength of different components of core veneered all-ceramic restorations. Part III: double veneer technique. J Prosthodont 2008;17:9–13.
[20] Grohmann P, Hammerle C, Sailer I. Three-unit posterior zirconia-ceramic fixed dental prothesis (FDPs) veneeres with layered and milled(CAD-on) veneering ceramics: 1-year follow-up of a randomized controlled clinical trial. Quintessence Int 2015;46(10):871–80.
[21] Kanat B, Cömlekoğlu EM, Dündar-Çömlekoğlu M, Hakan Sen B, Ozcan M, Ali Güngör M. Effect of various veneering techniques on mechanical strength of computer-controlled zirconia framework designs. J Prosthodont 2014;23(6): 445–55.
[22] Florian B, Josef S, Marlis E, Heinrich F, Wolfgang G, Daniel E. High-strength CAD/CAM-fabricated veneering material sintered to zirconia copings — a new-fabrication mode for all-ceramic restorations. Dent Mater 2009;25:121–8.
[23] Basso GR, Moraes RR, Borba M, Duan Y, Griggs JA, Della Bona A. Reliability and failure behavior of CAD-on fixed partial dentures. Dent Mater 2016;32(5): 624–30.

[24] Jeong ID, Bae SY, Kim DY, Kim JH, Kim WC. Translucency of zirconia-based pressable ceramics with different core and veneer thicknesses. J Prosthet Dent 2016;115(6):768–72.
[25] Kim Hee-Kyung, Kim Sung-Hun, Lee Jai-Bong, Han Jung-Suk, Yeo In-Sung, Ha Seung-Ryong. Effect of the amount of thickness reduction on color and translucency of dental monolithic zirconia ceramics. J Adv Prosthodont 2016;8(1):37–42.