Volume 3 / Issue 2 / December 2023

Research Article

Influence of Composition and Thickness on The Color and Translucency of Glass-Ceramic Materials for Laminate Veneer Restorations: An In Vitro study

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Yılmaz Savaş, Tuba., Yıldızlar, Seda. "Influence of Composition and Thickness on The Color and Translucency of Glass-Ceramic Materials for Laminate Veneer Restorations: An In Vitro Study". *Acta Stomatologica Cappadocia.* 3;2 (December 2023): 62-75
DOI: https://doi.org/10.54995/ASC.3.2.1
Received: 14.12.2023; Accepted: 25.12.2023

Influence of Composition and Thickness on The Color and Translucency of Glass-Ceramic Materials for Laminate Veneer Restorations: An In Vitro Study

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Abstract

Statement of the problem: Numerous glass-ceramic materials are commercially available, yet achieving optimal esthetic results relies significantly on material composition and thickness. The selection of suitable material and thickness poses an ongoing challenge in clinical practice.

Objective: This study aimed to investigate the effect of the composition and thickness of different glass-ceramic materials on the Commission Internationale de l'éclairage (CIE) L*, a*, and b* color coordinates and the translucency parameter (TP_{00}).

Materials & Methods: Glass-ceramic blocks of A2 shade, with low translucency, encompassing feldspathic (FS), leucite-reinforced feldspathic (LR), and lithium-disilicate (LD) compositions, were sectioned into three thicknesses: 0.5 mm, 0.7 mm, and 1 mm (n=10). All specimens were polished with ceramic polishing rubbers. Using a spectrophotometer, the CIE L*, a*, and b* color coordinates of the specimens were measured over gray, white, and black backgrounds. The TP_{00} was calculated using the CIEDE2000 color difference formula. The CIE L*, a*, b*, and TP_{00} were analyzed using two-way ANOVA and Tukey HSD post-hoc tests (α=0.05).

Results: Material, thickness, and their interaction significantly influenced the CIE L*, a*, b*, and TP_{00} values (P<0.001). The LR group displayed the highest L* and a* values, while the LD group showed the lowest (P<0.001). Conversely, the LD group exhibited the highest b* value (P<0.001). Lightness was lowest in 0.5 mm-thick specimens (P<0.001) and similar for 0.7 mm-thick and 1.0 mm-thick specimens (P>0.05). Redness and yellowness increased with increasing thickness (P<0.001). Regardless of thickness, the FS group had the highest TP_{00} (16.32±1.54), while the LR group had the lowest TP_{00} (14.31±1.67). Regardless of material, 0.5 mm-thick specimens demonstrated significantly higher TP_{00} (17.49±1.10) than 0.7 mm-thick (15.45±0.83) and 1.0 mm-thick (13.11±1.12) specimens. There was no significant difference between the 0.5 mm-thick FS and LD groups (P>0.05) and 1.0 mm-thick LR and LD groups (P>0.05).

Conclusions: Even when sharing the same shade, glass ceramics may exhibit varying color and translucency properties due to their distinct chemical compositions and thicknesses.

Keywords: Color, Ceramic, Glass-Ceramic, Translucency, Veneer

Introduction

Increasing esthetic expectations in dentistry and the rise of popularity of computer-aided design – computer-aided manufacturing (CAD-CAM) systems have contributed to the creation of materials with different compositions for various dental applications.[1,2] Among these innovations, glass-ceramic CAD-CAM blocks have emerged as highly esthetic options.[3] There are many options for glass-ceramic-based restorations, such as feldspathic ceramics, leucite-reinforced glass ceramics, and lithium disilicate glass ceramics.[4] The first CAD-CAM ceramic blocks were made primarily from feldspathic ceramics known for their excellent esthetics.[5] However, their durability limitations led to the development of leucite-reinforced glass ceramics. Although stronger than feldspathic ceramics, leucite-reinforced ceramics still experienced occasional failures.[5-7] To solve this problem, lithium disilicate ceramics were developed, initially for the heat-press technique and later for the CAD-CAM technique. Lithium disilicate offers superior durability while still being suitable for a variety of dental restorations such as crowns, veneers, and 3-unit fixed partial dentures up to premolars.[8]

Glass-ceramic laminate veneer restorations have become increasingly popular in the field of dentistry as an esthetic option,[9] because they offer improved esthetics and a more conservative treatment option compared to ceramic crowns.[10] These restorations provide remarkable translucency and consist of a thin layer of ceramic, ranging from 0.5 to 1.0 mm thickness, bonded to teeth using adhesive resin cement.[11] However, mimicking the optical properties of natural teeth with laminate veneers is challenging due to the minimal tooth preparation required.[12] The optical properties of ceramic laminate veneer restorations are influenced by several factors, including the type of ceramic material, thickness, background color, shade, and translucency of the ceramic material, and the color of the cement used.[13-15] For these reasons, it is difficult to achieve color harmony between ceramic laminate veneers and natural dentition.[16]

The translucency properties of ceramic materials are critical for achieving natural-looking ceramic restorations.[17] However, the enhanced translucency of thinner ceramics has added a new dimension of complexity to the color-matching process for ceramic laminate veneers.[18]

This challenge arises from the inherent differences in microstructural, chemical, and crystalline content of the various ceramic materials, which lead to variations in their optical properties.[19,20]

Currently, a wide range of glass-ceramic materials are commercially accessible in the market and the development of new materials brings about the need to investigate their esthetic properties and to compare them with existing materials. Moreover, although being manufactured industrially, these materials may exhibit varying optical qualities, even when they possess identical shades and translucency.[19,21] Therefore, the purpose of this study was to investigate the effect of the material composition and thickness on the Commission Internationale de l'éclairage (CIE) L*, a*, and b* color coordinates and the translucency parameter (TP_{00}) of different type of glass-ceramic materials. The null hypothesis of this study was that the different material compositions and thicknesses would not affect the CIE L*, a*, b* values, and translucency parameter of the glass-ceramic materials.

Materials & Methods

The study scheme is presented in Figure 1.

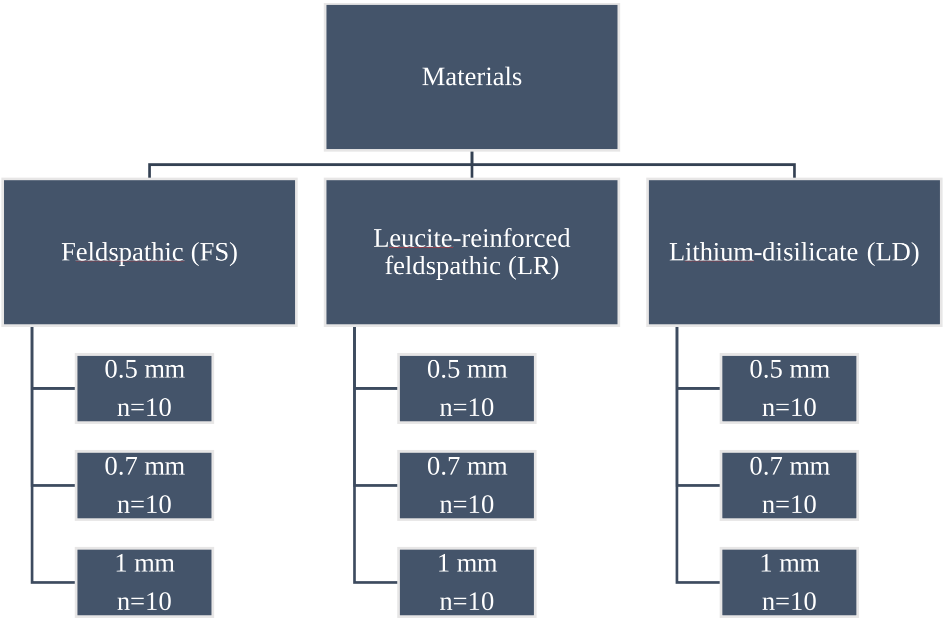

Figure 1. Study scheme.

Glass-ceramic CAD-CAM blocks of A2 shade, with low translucency, including feldspathic (FS, Cerec Blocks, Sirona Dentsply, Bensheim, Germany), leucite-reinforced feldspathic (LR, GC Initial LRF, GC Europe N.V., Leuven, Belgium), and lithium-disilicate (LD, IPS e.max CAD, Ivoclar Vivadent A.G., Schaan, Liechtenstein) compositions, were sectioned by using low-speed precision cutter (Isomet 1000, Buehler, Lake Bluff, IL, USA) into three thicknesses: 0.5 mm, 0.7 mm, and 1 mm (n=10). All specimens were grounded with 1000-grit silicon carbide abrasive papers and polished with ceramic polishing rubbers under water cooling (Ceramiste Polishers, Shofu, Kyoto, Japan). The thicknesses of all the specimens were checked with a digital caliper (Max Extra, Ningbo JL Measuring & Tool Co., China).

Color measurements of the specimens were measured over gray, white, and black backgrounds by using a dental spectrophotometer (Vita EasyShade V, Vita Zahnfabrik, Bad Säckingen, Germany). The probe tip of the spectrophotometer was placed over the middle of each specimen. Three measurements were made from each specimen over each background and the average CIE L*, a*, and b* values were recorded. The CIE L*, a*, and b* color coordinates were obtained over the gray background. The translucency parameter (TP_{00}) of the specimens was calculated from the color difference between the color of the specimen against the black and white backgrounds by using the following CIEDE2000 (ΔE_{00}) color difference formula:

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)\right]^{1/2}$$

The ΔE_{00} is a color difference formula that uses three parameters to quantify color differences between two samples: ΔL′ for lightness, ΔC′ for chroma, and ΔH′ for hue. Additionally, a parameter called RT (rotation function) accounts for the interaction between chroma and hue differences in the blue region. Moreover, ΔE_{00} utilizes weighting functions (SL, SC, SH) based on the location of the color difference within the L*a*b* color space and parametric factors (KL, KC, KH) to account for variations in experimental conditions. In this study, all parametric factors were set to 1.

Statistical analyses were conducted using a software program (SPSS Statistics, v26, IBM Corp, USA). Kolmogorov-Smirnov test was used to check the normality of the distribution of the data. Two-way analyses of variance (ANOVA), Tukey’s Honestly Significant Difference (HSD), and Bonferroni post-hoc tests were used to analyze the variables in a 95% confidence interval.

Results

Table 1 summarizes the two-way ANOVA results of the CIE L*, a*, b*, and TP_{00} values. Tables 2 to 5 present the means, standard deviations, and pairwise comparisons. The variables of material, thickness, and their interaction were found to have significant effects on the CIE L*, a*, b*, and TP_{00} values ($P<0.001$)(Table 1).

Table 1. Two-way ANOVA results of the CIE L*, a*, b*, and translucency parameter (TP_{00}).

Source	Type III Sum of Squares	Df	F	P	Partial Eta Squared
		CIE L*			
Material	186.348	2	530.604	<0.001	.929
Thickness	12.546	2	35.724	<0.001	.469
Material x Thickness	9.431	4	13.427	<0.001	.399
Error	14.224	81			
Total	432466.053	90			
		CIE a*			
Material	8.172	2	1585.109	<0.001	.975
Thickness	6.450	2	1251.152	<0.001	.969
Material x Thickness	1.275	4	123.669	<0.001	.859
Error	.209	81			
Total	61.931	90			
		CIE b*			
Material	365.927	2	1117.085	<0.001	.965
Thickness	216.318	2	660.364	<0.001	.942
Material x Thickness	12.129	4	18.514	<0.001	.478
Error	13.267	81			
Total	4847.946	90			
		Translucency Parameter (TP_{00})			
Material	60.674	2	150.090	<0.001	.788
Thickness	287.727	2	711.750	<0.001	.946
Material x Thickness	14.748	4	18.240	<0.001	.474
Error	16.372	81			
Total	21588.072	90			

The LR group had the highest L* and a* values, whereas the LD group demonstrated the lowest values (P<0.001) (Tables 2 and 3). In contrast, the LD group demonstrated the greatest b* value, with statistical significance at a level of P<0.001 (Table 4). The L* values were found to be significantly lower in the specimens with a thickness of 0.5 mm (P<0.001), whereas no significant difference in lightness was seen between the specimens with thicknesses of 0.7 mm and 1.0 mm (P>0.05)(Table 2). The study observed a significant positive relationship between thickness and the intensity of redness and yellowness (P<0.001).

Table 2. Means and standard deviations of the CIE L* values.

Material	**Thickness**			**Total**
	0.5 mm	**0.7 mm**	**1 mm**	
Cerec Blocks (FS)	69.07 ± 0.52^{a,A}	69.67 ± 0.20^{a,B}	69.79 ± 0.13^{a,B}	69.51 ± 0.45$^{\Omega}$
GC Initial LRF (LR)	70.92 ± 0.29^{b,A}	71.03 ± 0.36^{b,A}	70.90 ± 0.57^{b,A}	70.95 ± 0.42$^{\Sigma}$
E.max CAD (LD)	66.34 ± 0.30^{c,A}	67.82 ± 9.27^{c,B}	68.18 ± 0.74^{c,B}	67.44 ± 0.93$^{\lambda}$
Total	78.78 ± 1.95$^{\Theta}$	69.50 ± 1.37$^{\beta}$	69.62 ± 1.25$^{\beta}$	

Different lowercase superscript letters in the same column indicate significant differences in the same thickness (P<0.05). Different uppercase superscript letters in the same row indicate significant differences in the same material (P<0.05). Different superscript symbols indicate significant differences in the same row and in the same column (P<0.05).

Table 3. Means and standard deviations of the CIE a* values.

Material	**Thickness**			**Total**
	0.5 mm	**0.7 mm**	**1 mm**	
Cerec Blocks (FS)	-0.82 ± 0.04^{a,A}	-0.69 ± 0.04^{a,B}	-0.56 ± 0.03^{a,C}	-0.69 ± 0.11 $^{\Omega}$
GC Initial LRF (LR)	-0.70 ± 0.05^{b,A}	-0.42 ± 0.03^{b,B}	0.05 ± 0.08^{b,C}	-0.35 ± 0.32 $^{\Sigma}$
E.max CAD (LD)	-1.53 ± 0.02^{c,A}	-1.16 ± 0.06^{c,B}	-0.59 ± 0.07^{a,C}	-1.09 ± 0.40 $^{\lambda}$
Total	-1.02 ± 0.37 $^{\Theta}$	-0.76 ± 0.31 $^{\beta}$	-0.36 ± 0.31 $^{\Delta}$	

Different lowercase superscript letters in the same column indicate significant differences in the same thickness (P<0.05). Different uppercase superscript letters in the same row indicate significant differences in the same material (P<0.05). Different superscript symbols indicate significant differences in the same row and in the same column (P<0.05).

Table 4. Means and standard deviations of the CIE b* values.

Material	**Thickness**			**Total**
	0.5 mm	**0.7 mm**	**1 mm**	
Cerec Blocks (FS)	2.75 ± 0.47^{a,A}	3.93 ± 0.29^{a,B}	5.48 ± 0.31^{a,C}	4.06 ± 1.19$^{\Omega}$
GC Initial LRF (LR)	5.58 ± 0.55^{b,A}	7.48 ± 0.25^{b,B}	10.47 ± 0.43^{b,C}	7.84 ± 2.09$^{\Sigma}$

E.max CAD (LD)	$6.96 \pm 0.18^{c,A}$	$8.47 \pm 0.49^{c,B}$	$10.66 \pm 0.50^{b,C}$	$8.70 \pm 1.60^{\lambda}$
Total	$5.09 \pm 1.83^{\Theta}$	$6.63 \pm 2.01^{\beta}$	$8.87 \pm 2.47^{\Delta}$	

Different lowercase superscript letters in the same column indicate significant differences in the same thickness (P<0.05). Different uppercase superscript letters in the same row indicate significant differences in the same material (P<0.05). Different superscript symbols indicate significant differences in the same row and in the same column (P<0.05).

Regardless of thickness, the FS group exhibited the highest TP_{00} value (16.32±1.54), whilst the LR group had the lowest TP_{00} value (14.31±1.67) (Table 5). Regardless of the material used, specimens with a thickness of 0.5 mm exhibited a significantly greater TP_{00} value (17.49±1.10) compared to specimens with thicknesses of 0.7 mm (15.45±0.83) and 1.0 mm (13.11±1.12). There was no statistically significant difference observed between the groups with a thickness of 0.5 mm for FS and LD (P>0.05), as well as between the groups with a thickness of 1.0 mm for LR and LD (P>0.05).of this substance as an irrigant. There is a lack of information about the combination of PHMB and CHX with phytic acid, boric acid, peracetic acid, and hypochlorous acid. Therefore, this study is unique in its area to the best of our knowledge.

Table 5. Means and standard deviations of the TP_{00} values.

Material	**Thickness**			**Total**
	0.5 mm	**0.7 mm**	**1 mm**	
Cerec Blocks	$18.05 \pm 0.79^{b,C}$	$16.36 \pm 0.32^{c,B}$	$14.54 \pm 0.24^{b,A}$	$16.32 \pm 1.54^{\Omega}$
GC Initial LRF	$16.17 \pm 0.51^{a,C}$	$14.46 \pm 0.22^{a,B}$	$12.30 \pm 0.56^{a,A}$	$14.31 \pm 1.67^{\Sigma}$
E.max CAD	$18.24 \pm 0.34^{b,C}$	$15.54 \pm 0.23^{b,B}$	$12.48 \pm 0.48^{a,A}$	$15.42 \pm 2.42^{\lambda}$
Total	$17.49 \pm 1.10^{\Theta}$	$15.45 \pm 0.83^{\Delta}$	$13.11 \pm 1.12^{\beta}$	

Different lowercase superscript letters in the same column indicate significant differences in the same thickness (P<0.05). Different uppercase superscript letters in the same row indicate significant differences in the same material (P<0.05). Different superscript symbols indicate significant differences in the same row and in the same column (P<0.05).

Discussion

This in vitro study compared the effect of the material composition and thickness on the color properties of the three different CAD-CAM glass ceramics. Based on the findings, the

CIE L*, a*, b*, and TP_{00} values were significantly affected by the material composition and thickness. Therefore, the null hypothesis of this study was rejected. These results align with previous studies that have also demonstrated the effect of material composition on the optical properties of dental restorations.[13-15,21,22] Furthermore, the feldspathic ceramic, in particular, exhibited higher translucency compared to the leucite-reinforced and lithium disilicate glass-ceramics, which can be attributed to its composition and microstructure.[21,23-26]

Della Bona et al[20] investigated the impact of material composition on the translucency of CAD-CAM glass-ceramic materials. They stated that the presence of crystals in the ceramic matrix can significantly affect the translucency of the material, with the number of crystals adversely affecting the overall translucency.[20] While studies have shown that lithium disilicate glass ceramics may have reduced translucency compared with the feldspathic or leucite-based glass ceramics due to the presence of crystals,[13,19,20,25] other factors, such as the number and size of crystals, play a critical role in determining the final translucency of the material.[27] However, it is beneficial to consider an opposite point of view when it comes to the influence of material composition and thickness on the color coordinates and translucency of glass-ceramic materials. While the present study found that glass-ceramic materials with decreased thickness result in better translucency, a study conducted by Çömlekoğlu et al[28] found that the color masking ability of glass-ceramic laminate veneers was actually reduced as the thickness of the veneers decreased. They observed that when the veneers were too thin, the underlying color of the substrate became more visible, resulting in a less satisfactory esthetic outcome. They suggested ceramic veneers of at least 0.80 mm thickness or more to mask the color of the substrate.[28] Thus, it is crucial to properly evaluate the required thickness and level of translucency based on clinical requirements.

The effect of thickness on the translucency of ceramics has been emphasized in many studies.[14,29,30] It has been observed that as the thickness of ceramic material decreases, their translucency increases.[14,29,30] In this study, material type and thickness significantly affected the CIE L*, a*, b*, and TP_{00} of the ceramic materials used. While the CIE L* value was more affected by the material type, the thickness had a greater effect on translucency. The varying degrees of translucency observed in different thicknesses of the glass-ceramic laminate veneers can be attributed to the light scattering and transmission properties of the material.[31] As the thickness decreased, more light was able to pass through the veneer, resulting in increased translucency.[32] This observation is consistent with the principles of light transmission and scattering in dental ceramics.[33] These findings highlight the importance of carefully considering the material composition and thickness when selecting and fabricating glass-ceramic laminate veneers.[13] It is crucial to consider the color of the remaining tooth structure or core build-up material to achieve the desired level of translucency or masking ability.[14,22,28]

The limitations of this study include the use of in vitro test settings, the lack of aging, and the absence of the effect of the soft and hard tissues in the oral environment on the optical properties of ceramic materials. Additionally, the study is limited by the absence of cement and the use of a limited number of materials and shade. Future studies could investigate the mechanical and physical properties of newly introduced materials as well as the optical properties by using different cements, various shades, and translucencies under different in vitro and in vivo conditions.

Conclusions

Within the limitations of this study, the following conditions could be drawn:

1. The variables of material, thickness, and their interaction were found to have significant effects on the CIE L*, a*, b*, and TP_{00} values.

2. Leucite-reinforced glass ceramics showed the highest mean L* and a* value among the tested ceramics. The highest mean b* value was obtained in the lithium-disilicate-based glass-ceramic material.

3. The CIE L* and TP_{00} values were decreased, while the CIE a* and b* values were increased as the thickness increased from 0.5 mm to 1 mm.

4. The feldspathic CAD-CAM ceramic showed the highest TP_{00} mean value compared with the leucite-reinforced and lithium-disilicate-based glass ceramics.

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