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Comparative Analysis of Color Parameters of Two Core Materials: Effect of Repeated Firings, Porcelain Thickness and Shade

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Abstract

Objective: The purpose of this study was to investigate the color changes of two all-ceramic systems with two different veneering porcelain shades after recurrent firing procedures.

Methods: 84 disc-shaped specimens; 10 mm in diameter with a 0.5 mm core thickness and three different dentin thickness (0,5 mm-1 mm-1,5 mm) were made from each all-ceramic system (cercon®base-ZR and IPS e-Max). IPS e-max specimens were veneered with IPS e-Max Ceram (G1) both with A1 and A3 shades, Cercon®base-ZR specimens were veneered with Noritake Cerabien-CZR (G2) both with A1 and A3. The recurrent firing procedure (1,3,5) were repeated for each specimens and color differences were (a, b, L, ΔE) measured with a spectrophotometer (Vita Easy shade). Wilcoxon and Friedman test was used to determine the effect of veneer thickness and on the color parameters and t test were used for multiple comparisons. (p‹.05)

Results: As the ceramic thickness increased, significant decreases in L values (p‹.05) were recorded for IPS e-Max and cercon®base-ZR specimens. All L* a*b* values of the ceramic systems were affected by the number of firing procedures (1,3 and 5) (p‹.05).

Conclusion: Different veneering porcelain shades with two different ceramic systems influenced by the repeated firing procedure. The color changes that determined are clinically acceptable.

Keywords: *Color change; Dental ceramics; Recurrent firings; Spectrophotometer*

Introduction

Tooth is a double-layered structure that is composed of enamel overlying dentin. Dentin is the main determinant of tooth color, although the thickness and translucency of the enamel also affect tooth color. When performing a restoration in prosthetic dentistry, it can be a challenge to obtain the same color as the patient's natural teeth. When light falls on teeth, some light is reflected, some light is transmitted, and some light is scattered [1,2]. The light that is reflected from an enamel surface gives an observer a visual impression of a tooth's color [3]. It is important that a material reproduces the translucency and color of a patient's natural teeth, with the translucency providing vitality for the restoration [4-6].

The most common prosthodontic material used for crown and bridge restorations is porcelain fused to metal (PFM). However, while PFM restorations demonstrate very good mechanical strength, they typically are associated with unsatisfactory aesthetic results due to their metal core that transmits less light. This disadvantage can be eliminated with the use of all-ceramic restorations, which are fabricated from a high strength opaque core and less translucent veneering porcelain material. Satisfactory aesthetic results have been obtained with glass ceramics composed of leucite and lithium disilicate reinforced crystals [7]. However, these materials have demonstrated lower mechanical strength and are contraindicated in edentulous spaces with more than one pontic [8]. Thus, zirconia has developed as an alternative aesthetic material to glass ceramics based on its superior mechanical properties. However, zirconia has an opaque core and this significantly influences the color of the final restoration [9-11].

In order to compensate for the opacity of a core material and to achieve natural results, the thickness of the overlying porcelain can be increased. When Son., *et al*. recently measured the color of dentin porcelain of varying thicknesses according to the color space specified by the International Commission on Illumination CIE *L***a***b** (CIELAB), the CIE a* and b* values increased as the porcelain thickness increased [12]. However, clinically, available space is limited, and to preserve tooth health, not more than 2.0 mm of hard tissue should be removed so that the health of the supporting dentin tissue is not adversely affected [13]. Furthermore, even when adequate space exits for porcelain layering, satisfactory clinical color for restorations is not consistently achieved since ceramic translucency is also affected by factors such as ceramic microstructure [14], number of firings, brand, and shade [15-19]. The effects of these parameters in a layered ceramic system remain to be determined.

Optical behavior of restorative materials can be analyzed in two ways. The first is the visual analysis. However, the human eye has a limited capacity to identify small differences in color. This analysis is a subjective one. The second, an objective analysis is performed by instruments. The esthetic properties of dental restorations is being assessed with a spectrophotometer or a spectroradiometer (SR) using the Commision International e de l'Eclairage (CIE) L*a*b* coordinates [20]. These coordinates provide a numerical description of the color position in a 3-dimensional space. The L* represents the lightness in a range from 0 to 100. The a*coordinate represents greenness-redness and b* coordinate represents yellowness-blueness. The color difference (ΔE) expressed in L*, a*, b* is derived from this formula: ΔE* = ((ΔL*)2 +(Δa*)2 + (Δb*)2)1/2[15]

Therefore, the purpose of this study was to examine the color differences after recurrent firings between two core materials that were subjected to two different veneering porcelain shades in varying thicknesses. We hypothesized that the thickness of the veneering porcelain after recurrent firings would influence the final color, and this color difference would significantly differ between the shades and core materials used.

Material and Methods

Preparation of ceramic specimens

For IPS ceramic specimens (G1), (10 × 1 mm) wax patterns were prepared, were invested with a proprietary investment material (IPS PressVEST powder and liquid; IvoclarVivadent), and were placed in a furnace. After heating, the molten IPS ingot (MO1; IvoclarVivadent) was put into a muffle and pressed. The pressed cylinder was subsequently bench-cooled and divested using airborne-particle abrasion with 50-µm glass beads (Miniblaster; Belle de St. Claire, Encino, CA, USA). A1 and A3 shades of dentin powder were mixed and were layered on the cores using vibration and repeated fluid absorption procedures (IPS e.max Ceram; IvoclarVivadent). The condensed material was then placed on firing trays for drying and vacuum furnace firing (VITA Vacumat 40 T; VITA Zahnfabrik), by the manufacturer's instructions. The thickness of each group of specimens was then measured with a digital micrometer (Renfert GmbH, Hilzingen, Germany) with an accuracy of 0.05 mm, and corrected with diamond rotary cutting instruments (863-204-016; GebrBrasseler GmbH) until the desired thickness of dentin ceramic was achieved (0.5, 1, or 1.5 mm).

Preparation of zirconia specimens

Cercon (DeguDent, Hanau, Germany) wax patterns (10 × 1 mm) were prepared and the wax models were placed in a Cercon brain unit for scanning. A confocal laser system measured the wax to a precision of 10 ± 2 µm within 4 min. A Cercon base blank of pre-sintered zirconia was milled and then was sintered to a fully dense structure with the application of Cercon heat (1350°C) for 6h. The specimens were subsequently refrigerated, and then were subjected to airborne particle-abrasion with 100-µm aluminum oxide at a pressure of

3-bar (BegoKorox 50 and Korox 110, Bremen, Germany). A1 and A3 shades of dentin powder were mixed and were layered on the cores using vibration and repeated fluid absorption procedures (G2) (Noritake Cerabien-CZR).

Firing and thickness of specimens

Each set of condensed materials was then placed on firing trays for drying and vacuum furnace firing (VITA Vacumat 40 T; VITA Zahnfabrik), according to the manufacturer's instructions. One, three, and five repeated firings were performed for each group. The thickness of each group of specimens was measured with a digital micrometer (Renfert GmbH, Hilzingen, Germany), with an accuracy of 0.05 mm. To achieve the desired thickness of dentin ceramic (0.5, 1, or 1.5 mm), the specimens were corrected with a diamond rotary cutting instrument (863-204-016; GebrBrasseler GmbH).

Detection of color difference (ΔE)

The condensed material was then placed on firing trays for drying and vacuum furnace firing (VITA Vacumat 40 T; VITA Zahnfabrik), by the manufacturer's instructions. The thickness of each group of specimens was then measured with a digital micrometer (Renfert GmbH, Hilzingen, Germany) with an accuracy of 0.05 mm, and corrected with diamond rotary cutting instruments (863-204-016; GebrBrasseler GmbH) until the desired thickness of dentin ceramic was achieved (0.5, 1, or 1.5 mm). Repeated firings were performed for each group (1,3,5 firings). Color differences between specimens were measured with a spectrophotometer (VITA Easy shade; VITA Zahnfabrik) using the CIE L*a*b* coordinates as previously described [15,20]. The spectrophotometer's CIE L*a*b* output was based on a D65 illuminant and a 2-degree standard observer. For this study, three measurements were made and the instrument was recalibrated before each reading. The clinically acceptable limit of the color difference value is considered 3.7 ΔE units.

Data analysis

Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) version 21. The values that exhibited a non-homogenous distribution were evaluated with a non-parametric Wilcoxon test and the values that exhibited a normal distribution were evaluated with Student's t-test. Descriptive and homogeneity tests were performed. Wilcoxon and Friedman tests were used to determine the effect of veneer thickness and multiple firings on the color parameters. Tukey's post-hoc test was performed to identify multiple comparisons. ($P<0.05$)

Results

Initially, the mean ΔE, L, a*, and b* values for the ceramic and zirconia specimens (Groups 1 and 2, respectively) were calculated [Table 1]. Then, the ΔE values for the A1 and A3 shades (irrespective of thickness and firings) were statistically evaluated within each group and between both groups [Table 2]. The mean ΔE, L, a*, and b* values were also compared between Groups 1 and 2 [Tables 3, 4], followed by a comparison of ΔE, a*, b*, and L values for each core material according to shade [Table 5]. A comparison of the color parameters for the A1 shade exhibited a statistically significant difference between Groups 1 and 2 [Table 5]. Moreover, both the number of firings and porcelain thickness were found to affect the results obtained for the A1 shade for nearly all the groups, except the subgroup that had a 1.5 mm thickness and was fired five times. The same calculations were performed for A3 [Table 5], and the three subgroups with different thicknesses that were fired five times exhibited no statistically significant difference in their ΔE, a*, b*, and L parameters.

			ΔE			L			a*			b*		
Group	**Shade**	**Thick-ness [mm]**	**Firing 1**	**Firing 3**	**Firing 5**	**Firing 1**	**Firing 3**	**Firing 5**	**Firing 1**	**Firing 3**	**Firing 5**	**Firing 1**	**Firing 3**	**Firing 5**
1	A1	0.5	0.4	0.4	1.0	88.5	88.3	87.9	0.9	0.9	1.3	11.5	11.8	12.9
		1	0.6	0.6	1.1	86.7	86.7	87.0	1.2	1.4	1.6	13.6	13.9	13.9
		1.5	0.7	0.7	1.3	86.1	85.2	85.9	1.5	1.9	2.4	13.0	13.9	14.7
	A3	0.5	0.4	0.4	0.4	79.9	78.6	81.5	0.6	-0.2	0.2	18.3	19.3	20.1
		1	0.6	0.7	0.6	79.4	78.4	75.5	-0.3	-0.9	0.3	18.9	19.7	20.8
		1.5	0.6	0.9	0.6	78.8	77.7	76.1	0.1	0.5	0.9	18.0	19.9	21.7
2	A1	0.5	0.4	0.5	0.9	87.7	86.9	86.5	0.6	0.9	1.3	11.3	11.5	12.5
		1	0.7	0.6	1.0	87.1	86.5	78.4	1.1	1.0	1.6	13.6	13.8	14.1
		1.5	0.7	0.9	1.2	86.1	85.8	85.2	1.5	1.2	2.4	13.9	14.5	15.4
	A3	0.5	0.4	0.6	0.7	80.1	78.5	78.1	-0.6	-0.3	0.3	17.7	18.6	19.5
		1	0.6	0.7	0.8	80.8	79.3	78.9	-0.4	0.1	0.5	18.5	19.2	19.8
		1.5	0.7	0.9	1.2	80.2	80.7	78.9	-0.2	0.5	1.2	18.4	19.5	21.3

Table 1: *Mean ΔE, L, a*, and b* values for Groups 1 and 2 according to specimen thickness and number of repeated firings.*

Parameters	**Group 1**		**Group 2**	
evaluated	**A1**	**A3**	**A1**	**A3**
N	30	30	30	30
Chi-square	2.467	57.068	0.119	60.000
Df	2	2	2	2
Asymp. Sig	0.000	0.000	0.000	0.000

Table 2: *Comparison of ΔE values for both shades for Groups 1 and 2.*
Df: -; Aymp. Sig.: asymptotic significance.

			ΔE	**L**	**a**	**b**
Shade A1 [G1/G2]	Firing 1	Z Asymp.Sig [2-tailed]		-3.497[a].000		-.882[a] .378
	Firing 3	Z Asymp.Sig [2-tailed]	-3.386[a] .001	-2.282[a] .023	-.981[a] .326	
	Firing 5	Z Asymp.Sig [2-tailed]	-2.527[a] .012	-.573[a] .567	-.415[a] .678	
Shade A3 [G1/G2]	Firing 1	Z Asymp.Sig [2-tailed]	-2.249[a] .024		-1.991[a] .046	
	Firing 3	Z Asymp.Sig [2-tailed]		-811[a] .417		
	Firing 5	Z Asymp.Sig [2-tailed]	-3.191[a] .001	-1.189[a] .234	-2.202[a] .028	-3.240[a] .001

Table 3: *Comparison of mean ΔE, L, a*, and b* values for Groups 1 [G1] and 2 [G2] after each firing in regard to shade.*
[a]Based on positive ranks. Italic font indicates a statistically significant difference. Asymp. Sig.: asymptotic significance.

Shade	Firing		Paired Differences					t	df	Signif. [2-tailed]
			Mean	SD	SEM	95% CI of the Difference				
						Lower	Upper			
Shade A1 [G1/G2]	Firing 1	ΔE	-0.09333	0.14368	0.02623	-0.14698	-0.03968	-3.558	29	0.001
		a	0.14867	0.26778	0.04889	0.04867	0.24866	3.041	29	0.005
	Firing 3	b	-0.08567	0.84009	0.15338	-0.39936	0.22803	-0.559	29	0.581
	Firing 5	b	-0.38533	0.79590	0.14531	-0.68253	-0.08814	-2.652	29	0.013
Shade A3 [G1/G2]	Firing 1	L	0.03133	0.28008	0.05114	-0.07325	0.13592	0.613	29	0.545
		b	0.19233	0.89120	0.16271	-0.14045	0.52511	1.182	29	0.247
	Firing 3	ΔE	-0.11000	0.21552	0.03935	-0.19048	-0.02952	-2.796	29	0.009
		a	0.04400	0.22703	0.04145	-0.04077	0.12877	1.062	29	0.297
		b	0.50033	0.91573	0.16719	0.15840	0.84227	2.993	29	0.006

Table 4: *Statistical comparisons of the color parameters detected for the Group 1 and Group 2 specimens after each firing in regard to shade.*
SD: standard deviation; SEM: standard error of the mean; CI: confidence interval.

Group/		DE	L	a*	b*								
Firing	A1-A3	0.5 mm	1 mm	1.5 mm	0.5 mm	1 mm	1.5 mm	0.5 mm	1 mm	1.5 mm	0.5 mm	1 mm	1.5 mm
Group 1													
Firing 1	Z	-1.342[a]	-1.732[a]	-1.604[a]	-2.803[a]	-2.803[a]	-2.803[a]	-2.803[a]	-2.805[a]	-2.803[a]	-2.803[a]	-2.803[a]	-2.803[a]
	Asymp. Sig. [2-tailed]	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Firing 3	Z	-2.124[a]	-.108[a]	-2.536[a]	-2.803[a]	-2.803[a]	-2.803[a]	-2.805[a]	-2.803[a]	-2.805[a]	-2.805[a]	-2.803[a]	-2.803[a]
	Asymp. Sig. [2-tailed]	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Firing 5	Z	-2.371[a]	-2.825[a]	-2.680[a]	-2.803[a]	-2.803[a]	-1.988[a]	-2.803[a]	-2.805[a]	-2.803[a]	-2.805[a]	-2.803[a]	-2.803[a]
	Asymp. Sig. [2-tailed]	0.005	0.005	0.007	0.005	0.005	0.047	0.005	0.005	0.005	0.005	0.005	0.005
Group 2													
Firing 1	Z	-0.850[a]	-0.431[a]	-0.367[a]	-2.803[a]	-2.803[a]	-2.803[a]	-2.703[a]	-2.805[a]	-2.803[a]	-2.803[a]	-2.803[a]	-2.803[a]
	Asymp. Sig [2-tailed]	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Firing 3	Z	-0.852[a]	-1.150[a]	-0.845[a]	-2.803[a]	-2.803[a]	-2.803[a]	-2.805[a]	-2.803[a]	-2.805[a]	-2.805[a]	-2.803[a]	-2.803[a]
	Asymp. Sig. [2-tailed]	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Firing 5	Z	-2.178[a]	-2.417[a]	-1.196[a]	-2.803[a]	-1.784[a]	-1.274[a]	-2.803[a]	-2.805[a]	-2.803[a]	-2.805[a]	-2.803[a]	-2.803[a]
	Asymp. Sig. [2-tailed]	0.029	0.016	0.232	0.005	0.074	0.203	0.005	0.005	0.005	0.005	0.005	0.005

Table 5: *Comparison of ΔE, L, a*, and b* values for the A1 and A3 shades after each firing and for all thicknesses for Groups 1 and 2.*

Discussion

The current study investigated the differences that were detected using the CIELAB color system for ceramic versus zirconia core materials that were subjected to various porcelain thicknesses, shades, and numbers of firings. The results obtained support the hypothesis that color differences exist relative to the core material and shade used for restorations. Specifically, the ΔE, a*, b*, and L values differed according to the number of repeated firings and as the thickness of the applied porcelain increased.

Contradictory results have been reported in the literature regarding the threshold value of ΔE that is needed for an acceptable color difference. For example; in a recent study, dentists reported that they would repeat a restoration due to color mismatch when the ΔE value was 5.5 [21]. Some authors have reported that a color change of 1-2 CIE units can be detected by most observers [22-24], (yet these differences were still accepted as a match) while others have found that differences less than 3.7 ΔE units are acceptable for designation as a match [25,26]. This contradiction can be explained by the factors related to the testing environment. For example, under perfectly controlled in vitro conditions, in contrast with uncontrolled clinical conditions, small color differences would be detectable and the perceptible threshold could be much lower. In the present study, the mean color difference (ΔE) was between 0.4 and 1.2 [Table 1]. If $\Delta E > 3.7$ is considered the threshold for a clinically perceptible color change [26], then the color differences detected in the present study would not be detected by the human eye and would be rated as a match with the environment. Accordingly, the differences would not be clinically relevant.

In the current study, the lightness behavior of the ceramic and zirconia core materials that were tested was similar, and they remained similar when two different shades for each material were achieved. Shades A1 and A3 were affected by the number of repeated firings, the porcelain thickness, and the core material [Table 2]. Correspondingly, a* and b* values of the CIELAB system were affected by these three parameters as well. Specifically, an increase in porcelain thickness resulted in higher a* (red) and b* (yellow) values in both groups, and these results are consistent with those of previous studies [15,22,27,28]. Furthermore, the increase in a* (red) and b* (yellow) values were led to change the color. The L values were also affected by the number of firings and porcelain thickness. Similar to previous studies, as the porcelain thickness increased, the L values decreased [12,29]. The greater number of firings and increased porcelain thickness also resulted in reduced brightness. When the porcelain thickness increased only slightly (e.g., by 0.5 mm), a corresponding slight decrease in the L values was observed, and the associated color difference was not perceptible (e.g., the ΔE was between 0.4 and 1.2). This result is attributed to the translucent characteristics of porcelain, whereby an increase in dentin porcelain thickness increases the amount of light that is scattered and absorbed, which leads to less light being reflected back. This difference was more evident in the zirconia groups. The zirconia groups consistently showed worse color results than the glass ceramics containing leucite and lithium-disilicate reinforced crystals, as demonstrated by the higher a*, b*, and L values that were detected [Table 1]. The lower crystalline matrix content of the IPS e-MAX also probably allowed for a higher rate of light transmission, and this would result in greater brightness compared with the zirconia core since the amount of light that is absorbed, reflected, and transmitted has been shown to depend on the crystalline content of a core material [30]. A higher crystalline content in a core also results in greater mechanical strength and opacity, and this was observed in the present study as in previous studies [31,32]. However, an opaque core is not necessarily a negative characteristic. For example, in situations where a discolored tooth remnant, amalgam, metallic post, and core are present, zirconia cores may be preferable. It is important that clinicians and dental technicians are familiar with the different translucent properties of core materials in order to select the appropriate material for a specific clinical situation.

Based on the results of the current investigation, an increase in the number of repeated firings was found to affect all of the color parameters, albeit minimally. For example, the difference after one versus three firings was less than that after five firings. Previously, O'Brien., et al. demonstrated that up to six repeated firings results in perceived color changes [18] In the present study, up to five repeated firings were performed, although a restoration should generally be fired at least two times (1 enamel, 1 dentin). Subsequently, the technician has to be able to shape the restoration to achieve the desired natural look within a certain number of firings. Color changes that occur after repeated firings have been attributed to the instability of certain metal oxides during firing. Metal oxides are added to ceramic material to obtain the appropriate color. Previous studies have reported that repeated firings result in a decrease in L values and an increase in a* and b* values [33] and that was also observed in the present study.

In the present study, 2 veneering porcelain shades were selected: A1 and A3. The results showed that A1 shade specimens' L* value independent of the number of firings, whereas A3 shade specimens became darker after an increased number of firings, and higher ΔE values were observed in A1 than A3 porcelain veneering material. [Table 1, Table 3] Both the number of firings and porcelain thickness were found to affect the results obtained for the A1 shade for nearly all the groups in G1, except the subgroup that had a 1.5 mm thickness and was fired five times. In the same way; both the number of firings and porcelain thickness were found to affect the results obtained for the A3 shade for nearly all the groups in G1, except the subgroups that in all thickness and was fired five times. [Table 4, Table 5] G1 and G2 have different core substructures that may have influenced the translucency and color differences. When the translucency change, this may be affect the differences in core crystal volume and refractive index [9].

Conclusion

The clinical relevance of the current investigation is somewhat limited since porcelain specimens with flat surfaces were used, no enamel porcelain was used, and the effect of a luting agent was not investigated. Both porcelain thickness and the number of firings affect the color of specimens both in shade A1 and A3. A1 shade specimens' L* value independent of the number of firings, whereas A3 shade specimens became darker after an increased number of firings, and higher ΔE values were observed in A1 than A3 porcelain veneering material. G1 and G2 have different core substructures that may have influenced the translucency and therefore the color differences. Regarding the former, measurements of color parameter changes for a flat surface do not represent a clinical situation since natural teeth have curved surfaces. Regarding the latter, all-ceramic restorations are luted to a tooth substrate with an agent, and this agent has its own shade and thickness that can affect a restoration. Therefore, additional studies are needed to consider the effects of these factors on the color of a restoration, particularly as they relate to clinical conditions.

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