Eur. J. Prosthodont. Rest. Dent., Vol.21, No. 2, pp 88-94
Printed in Great Britain

doi:10.1922/EJPRD_1116ALDwairi07

Influence of Dentine Thickness and Repeated Firing on the Colour of IPS e.max Press

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Abstract - *The purpose of this study was to determine the possible effects of the veneering porcelain thickness, and of repeated firing on the final shade of IPS e.max Press. Sixty disc-shaped IPS e.max Press specimens were fabricated and divided into 6 groups according to shade (A2, C2) and porcelain thickness (0.5, 1.0 and 1.5 mm). Repeated firing (3, 5 and 7 firings) was performed and the colour differences (ΔE) were determined. With increased thickness, A2 specimens showed a significant reduction in L* values and increase in a* and b* values while C2 specimens showed reductions in L*a*b values (P < 0.01). We would conclude that clinically, the preparation should provide at least 1 mm of thickness for the aesthetic potential of this dentine porcelain to be realized.*

KEY WORDS: Firing, Shade, Colour difference, Porcelain

INTRODUCTION

Clinically, it is important for ceramic restorations to reproduce the translucency and colour of natural teeth [1-5]. There are, however, many components affecting the match, such as translucency, opalescence[6], fluorescence, surface texture and shape[7]. Many ceramic systems have layered veneering porcelains[8], because the relatively opaque core materials contribute to the overall colour of the restoration.' Thus, controlling the ultimate translucency of the core and veneering system is important for achieving the desired aesthetic results[9].

It has been concluded that there was not enough evidence to support an all-ceramic material for all clinical situations, and successful application of the all-ceramic restoration depends on the ability to select the appropriate material, manufacturing techniques, cementation procedure, bonding and matching aesthetic requirements[10]. IPS e.max Press (Ivoclar Vivadent, Schaan, Liechtenstein), a lithium-disilicate glass ceramic was introduced in 2005 as an improved press-ceramic material compared to IPS Empress 2[11,12].

Colour assessment is regarded as a complex psycho-physiologic process subject to numerous variables[13,14]. The Commission Internationale de l'Eclairage (CIE) recommended calculating colour difference (ΔE) based on CIELAB (CIE L*a*b*) color parameters [15]. The ΔE values are used to describe whether the changes in the overall shade are perceivable to the human observer. This magnitude of the colour difference is based on the human perception of colour where differences greater than 1 ΔE unit are visually detectable by 50% of human observers[16]. However, under uncontrolled clinical conditions, such small differences in colour would be unnoticeable because average colour differences below 3.7 have been rated as a match in the oral environment[14].

The shade duplication phase encompasses many variables that can have isolated or cumulative negative effects on the final outcome[17]. Variables that have been investigated include restoration thickness[13,18,19], type of crown substrate and veneer material choice[7,20-23], firing temperature and frequency and technical skill[24-27]. An accurate initial shade selection does not necessarily lead to an acceptably matched final restoration[6].

Studies examining colour changes of surface colorants after firing have demonstrated pigment breakdown at firing temperatures[28,29]. Specific contributions of core and veneer thickness to the appearance of layered ceramics were determined[25] and it was concluded that there was a significant correlation between the thickness ratio of core and veneer ceramics and the colour of the restoration. In addition, Heffernan et al [7,20] concluded that the thickness and the combination of ceramic layers, such as the core, veneer, and other specialty ceramic materials, have been shown to control the appearance of all-ceramic materials.

The effect of multiple firings has also been investigated in some previous studies which reported that repeated firings did not noticeably affect the colour of dental ceramics.[17,30,31]. However, other studies[13,32-35] reported perceptual colour changes in color parameters as the number of firings increases.

To the best of the authors' knowledge, no previous studies investigated the effect of thickness of the veneering porcelain and the number of firing cycles on the final shade of IPS e.max Press. Therefore, this in-vitro study aimed to determine the possible effects of the veneering porcelain thickness, and of repeated firings on the final shade of two different shades of IPS e.max Press. The null hypothesis is that discrepancies in colour would not occur relative to different thicknesses, different veneering porcelain shades, and the number of firings.

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MATERIALS AND METHODS

Specimen fabrication

Sixty disc-shaped specimens were fabricated from IPS e.max Press (Ivoclar Vivadent, Schaan, Liechtenstein). Wax patterns (11 mm × 1 mm) were prepared, invested in a phosphate-bonded investment material (IPS Press speed; Ivoclar Vivadent) following the manufacturer instructions, and burned out in a furnace (VITA Vacumate 300; VITA Zahnfabrik) at 850ºC. IPS e.max Press medium opacity (MO1) ingots were used to fabricate A2 shade specimens (30 specimens) while MO4 were used to fabricate C2 shade specimens (30 specimens) to the intended thickness and diameter. The specimens were heat-pressed (IPS Empress EP500 Pressing Furnace; Ivoclar Vivadent) at 920ºC. The muffle was then removed and the investment air cooled. After that, the specimens were divested using airborne particles with 50 micron glass beads (Korox; BEGO).

Dentine porcelain application

The specimens were divided into two groups, the first group consisted of 30 disc-shaped cores that were fabricated from MO1 ingots; this group was veneered with A2 shade veneering porcelain (VITA Classical Shade Guide; VITA Zahnfabrik) shade dentine porcelain (IPS e.max Ceram; Ivoclar Vivadent) to different thicknesses, to reach the final thickness. The second group, consisted of 30 specimen disc-shaped cores that were fabricated from MO4 ingots, veneered with C2 shade veneering porcelain (VITA Classical Shade Guide; VITA Zahnfabrik) shade dentine porcelain (IPS e.max Ceram; Ivoclar Vivadent) to different thicknesses, to reach the final thickness.

Dentine porcelain slurry enough for 10 specimens was condensed following manufacturer's instructions and hand vibrated and absorbent paper tissue was used to remove excess moisture to reduce porosity. Dentine porcelain was slightly over built. The thickness was measured using a manual micrometer and adjustments to the required thickness was carried out using a diamond rotary cutting instruments (Brasseler GmbH, Germany). Four points were measured on each specimen to obtain a mean to achieve the required thickness of porcelain addition. Firing for all specimens was carried out in a porcelain oven (Ugin Dentaria C100 ®, France) at 725°C; it was performed following manufacturer instructions.

Colour Measurements

The colour coordinates of each specimen were measured using a Colorimeter (Compact Easyshade® VITA Zahnfabrik, California), (Figure 1). The colorimeter head was placed on the centre of each specimen, (Figure 2). The device was calibrated before taking the colour coordination of each group by applying the probe tip to the on-board calibration block for three seconds[13].

This hand-held system captures the colour coordinates using a contact probing tip that is about 5 mm in diameter. During the measurement process, the tooth is illuminated by the periphery of the tip, directing the light from a halogen bulb in the base unit onto the tooth surface. In the centre of the probe tip there are a number of filters and sensors that receive the scattered light and convert this scattered light into different forms of data that are displayed on a small screen (Figure 1). The colour of the specimen was measured with the glazed surface facing up against a white background. The data were displayed in L*, a*, and b* values, according to the CIELAB system. The shade determination of the specimens was made three times for each sample, consecutively, and averages of L*, a* and b* values were recorded.

Colour difference (ΔE) was calculated for differences in L*, a* and b* values between each group. The colour difference ΔE* in the CIE L*a*b* system is defined as:

$$\Delta E^* = [(L_1-L_2)^2 + (a_1-a_2)^2 + (b_1-b_2)^2]^{1/2}$$

Where $\Delta L^*(L_1-L_2)$ is the difference in lightness of the specimen, $\Delta a^*(a_1-a_2)$ is the difference of chroma along the red-green axis and $\Delta b^*(b_1-b_2)$ is the difference of chroma along the yellow-blue axis, between the CIE L*a*b* colour parameter of two samples[14].

Figure 1. *The Colorimeter (Compact Easyshade® VITA Zahnfabrik, California) used in the study.*

Figure 2. *The colorimeter tip was placed in the center of each specimen with the glazed surface facing up against a white background.*

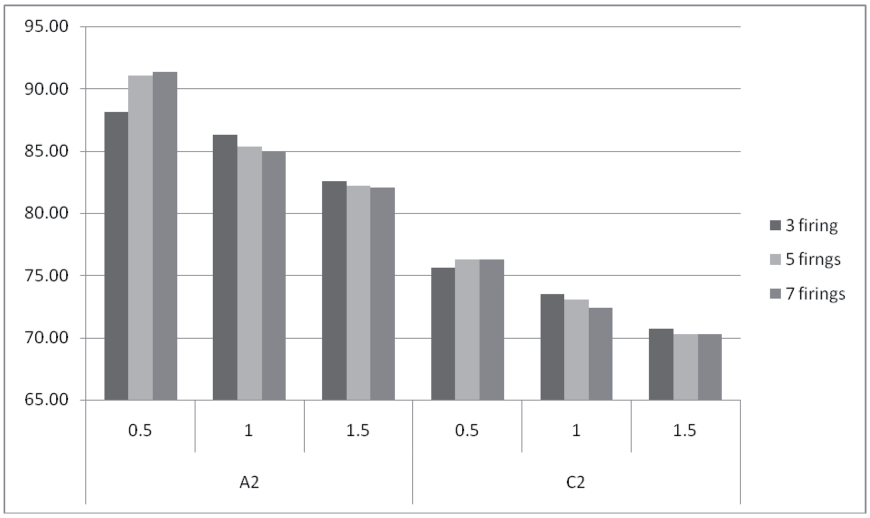

Figure 3: *Mean value of L* for different ceramic thicknesses and shades.*

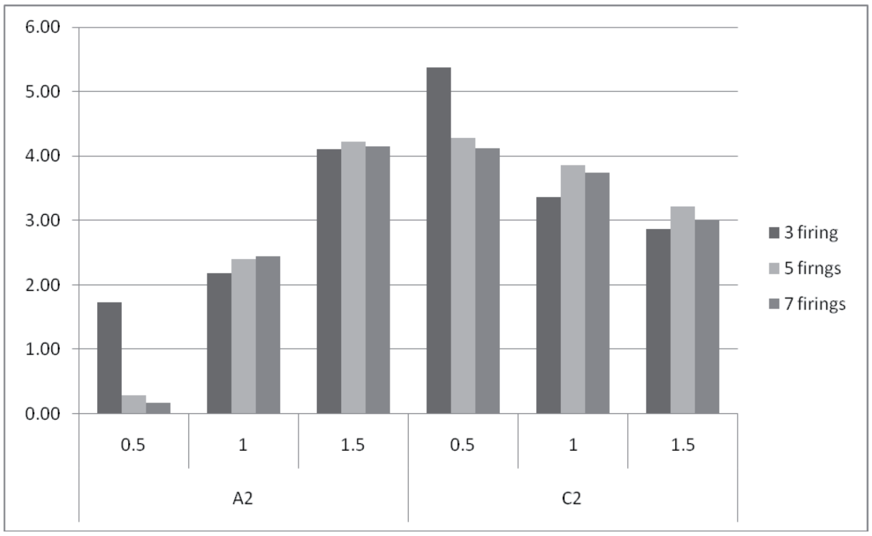

Figure 4: *Mean a* value for different thicknesses and shades*

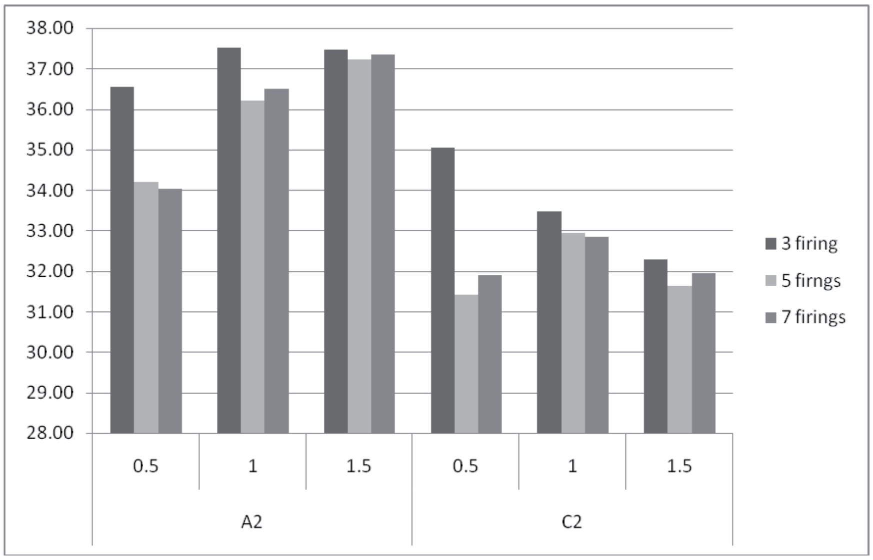

Figure 5: *Mean b* value for different thicknesses and shades.*

Table 1: *Multivariate test ANOVA results for changes in color coordinates after repeated firing of IPS e.max Press specimens.*

Parameter	*Effect*	*Pillai's value*	*Df*	*F*	*P value**
ΔL	Number of firing	0.350	2.00	0.708	.494
	Number of firing × Shade	0.075	2.00	1.751	.177
	Number of firing × Thickness	0.623	4.00	11.419	<.01
	Number of firing × shade × thickness	0.991	6.00	6.894	<.01
Δa	Number of firing	0.363	2.00	10.065	<.01
	Number of firing × Shade	0.079	2.00	1.793	.170
	Number of firing × Thickness	0.487	4.00	32.850	<.01
	Number of firing × shade × thickness	0.895	6.00	181.202	<.01
Δb	Number of firing	0.359	2.00	33.095	<.01
	Number of firing × Shade	0.069	2.00	0.294	.745
	Number of firing × Thickness	0.576	4.00	10.727	<.01
	Number of firing × shade × thickness	0.877	6.00	12.297	<.01

*P <.05 indicates a significant difference

Data Analysis

The data were analysed using statistical software (SPSS PC, Vers.17.0; SPSS, Chicago, Ill). Repeated-measures of analysis of variance (ANOVA) was used to analyse the data (number of firings, ceramic shade, and ceramic thickness) for significant differences. The Tukey honestly significant difference (HSD) test and paired 2-tailed tests were used to perform multiple comparisons (α = 05).

Table 2: *Mean ΔE values for A2 and C2 IPS e.max Press specimens at different thicknesses after the first firing*

Ceramic Thickness (mm)	*ΔE (A2)±SD*	*ΔE (C2) ±SD*
0.5-1.0	2.1±0.01	3.3±0.11
1.0-1.5	4.2±0.03	3.1±0.13
0.5-1.5	10.6±0.12	6.2±0.15

RESULTS

Figure 3 demonstrates the mean L* value for groups with different dentine thicknesses and different shades. The lightest group was the A2 shade group with 0.5 mm dentine thickness after the seventh firing cycle with a mean L* = 92 ± 0.25. The lightness was decreased by the increase in the thickness of the veneering porcelain; in addition, the A2 shade groups were lighter than the C2 shade groups.

The mean redness chromaticity for different thicknesses and shades after repeated firing cycles is demonstrated in Figure 4. The highest redness group was the C2 shade group with 0.5 mm dentine thickness at three firing cycles (a*= 5.5 ± 0.34), and the lowest redness group was the A2 group with 0.5 mm dentine thickness after seven firing cycles (a*= 0.5 ± 0.20). Also, the redness increased for the A2 group when the thickness of the veneering porcelain increased, while it's decreased for the C2 groups.

The mean yellowness chromaticity for different shades and thicknesses groups after multiple firing cycles is demonstrated in Figure 5. It can be noticed that the A2 groups had a higher b* value (mean b* = 37.5 ± 0.50) than that for the C2 groups (mean b* = 31.34 ± 0.17). Also it can be noticed that the yellowness chromaticity is increased when the dentine thickness is increased for the A2 shade samples while it varied for the C2 shade samples.

Table 1 shows that as the ceramic thickness increased, a significant reduction occured in the L* values ($P < 0.01$) and an increase in a* and b* values ($P < 0.001$) was recorded for the A2 shade specimens. For the C2 shade specimens, reductions in L*a*b values ($P < 0.01$) were observed; however, no significant difference was recorded for the b*value between 1.5 and 1.0 mm thickness for this shade ($P = 0.534$).

An increase in the number of firings resulted in a significant increase in a* value ($P < 0.01$) for the 1.0 and 1.5 thickness specimens in both shades between the fifth firing cycle and the baseline measurements, while there was a significant reduction in redness chromaticity in the 0.5 mm thickness specimens for both shades and all firing cycles ($P < 0.01$). In addition, the b* values ($P < 0.01$) were significantly reduced after repeated firings, for all the thicknesses and both shades between the fifth firing cycle and the baseline measurements. However, the effect of repeated firing was not significant for the a* and b* values between the fifth and the seventh firings for both shades. The lightness of all specimens was not affected significantly by the number of firings ($P = 0.732$).

Colour Difference Measurements

Calculated mean colour difference (ΔE) values were within the clinically unnoticeable range between the 0.5 mm and the 1 mm thicknesses (ΔE<3.7) for both shades, but it was high between the 0.5 mm and 1.5 mm (ΔE>3.7) (Table 2). Also, the colour difference (ΔE) was within the clinically acceptable range between the 1 mm and 1.5 mm thicknesses for the C2 groups, but it was higher for the A2 group.

For the A2 specimens, the colour difference (ΔE) value was high for the 0.5 mm thickness specimens between firing cycles. However, for the C2 specimens, the ΔE value was within the clinically acceptable range between the firings for all thicknesses, except between the third and the fifth firing cycles (Table 3).

The colour differences between the fifth and the seventh firings for both shades were less than 1 unit (ΔE<1).

Table 3: *Mean ΔE values for A2 and C2 IPS e.max Press specimens at different thicknesses and after repeated firing.*

Shade	Number of firings	ΔE±SD (at 0.5mm)	ΔE±SD (at 1.0 mm)	ΔE±SD (at 1.5 mm)
A2	3-5	4.0±0.31	1.6±0.31	0.4±0.11
	5-7	0.4±0.03	0.5±0.32	0.2±0.43
	3-7	4.7±0.11	1.7±0.51	0.5±0.41
C2	3-5	3.8±0.01	0.9±0.01	0.8±0.21
	5-7	0.5±0.21	0.6±0.32	0.4±0.03
	3-7	3.4±0.41	1.3±0.022	0.6±0.16

DISCUSSION

The increased demand for aesthetic restorations has resulted in the use of ceramic restorations in several applications[13]. Recently, new dental materials and techniques have been introduced to fabricate aesthetic ceramic restorations with improved strength and marginal adaptation. According to the manufacturer, IPS e.max Press is a lithium disilicate glass ceramic that has optimized translucency, durability and strength for full anatomical restorations. Due to the use of new technologies and optimized processing parameters, IPS e.max lithium disilicate has evolved beyond previously available lithium disilicate ceramics. Also, IPS e.max lithium disilicate restorations exhibit superior durability featuring 360-400 MPa of flexural strength[36]. According to the manufacturer, the opalescence, translucency and light diffusion properties of IPS e.max Press were all designed to replicate natural tooth structure for beauty and undetectable restorations.

This in-vitro study measured the colour changes of ceramic specimens (IPS e.max Press), prepared with different veneering porcelain shades, thicknesses, and firings cycles. The results of this study reject the null hypothesis that discrepancies in colour would not occur relative to different thicknesses, veneering porcelain shades, and the number of firings. The results showed that repeated firing did not significantly affect the lightness of both shades, and an increase in the number of firings resulted in a significant increase in a* value for the 1.0 mm and 1.5 mm thickness specimens in both shades, while there was a significant reduction in redness chromaticity in the 0.5 mm thickness specimens for both shades. In addition, the b* values were significantly reduced after repeated firings, for all the thicknesses and both shades.

In the present investigation, two veneering porcelain shades, A2 and C2, were selected. One shade from the "A" group was selected, since this group accounts for at least 65% of clinical shade selection and most teeth shades in young patients are in the "A" group whilst the teeth in middle aged and elderly people may appear duller to became in the "C" group[37,38].

Sahin et al [35] evaluated the changes in colour of an alumina ceramic system veneered with different dentine porcelain shades and different fired numbers cycles. The authors found that A1 shade specimens maintained their L* value and it was not affected by the number of firings, whilst the A3 shade specimens became lighter after an increased number of firings. Also, for both A1 and A3 veneering porcelain shades, a* value decreased after repeated firings, which resulted in greener specimens, and the b* value decreased after repeated firings, which resulted in less yellowish specimens.

In the current study, the interpretation of data achieved with a CIELAB system visually facilitated the comparison of the objective data with the subjective investigation. The numeric data of colour coordinates are useful in analysing the overall significance of the perceived colour dilemma, but they do not provide helpful visual information. Therefore, the graphic analysis of the measured CIELAB colour values provided visually related information that can be applied to the analysis and management of colour-related problems [39]. The ΔE value after repeated firing was undetectable for both shades specimens (ΔE<1) for 1.5-mm-thick specimens fired 7 times, and just detectable at perceivable levels for the 1mm-thick specimens.

Conversely, statistically analysed a* and b* colour parameters showed significant differences with repeated firing. It was observed that a* colour values increased after repeated firing, except for 0.5 mm-thick specimens, resulting in specimens of ceramics that were redder and more yellow, and it was observed that b* colour values decreased after repeated firing, except for 0.5 mm-thick specimens, resulting in specimens of ceramics that were greener and less yellow. Furthermore, colour changes occurred, especially after 3 firings, and less colour change was observed with subsequent firing.

Colour change after repeated firings may also be partly attributed to the instability of metal oxides color during firing, which can affect the final shade of the ceramic. Several studies[28,29,40] proposed that certain metal oxides are colour unstable after they were subjected to different firing temperatures. Crispin et al[28] and Lund and Piotrowski[40] reported that yellow and orange hue stains were the highest color unstable stains at the manufacturers' recommended firing temperatures. Mulla and Weiner[29] indicated that blue was the least stable stain, whilst orange demonstrated the highest color stability at high firing temperatures.

The results showed that lower ΔE values were observed in the C2 than the A2 porcelain veneering material. Clinical success and colour stability of all-ceramic restorations depend on laboratory and clinical variables. The ceramic system in this study possessed acceptable visual colour changes after firing when the thickness of veneering porcelain is 1 mm or higher, and when manufacturers' instructions were followed. The specimens of the 0.5 mm thickness was influenced more than other specimens' thicknesses, this may be due to inability of 0.5 mm of thickness to mask the changes that might occur to the core material.

Most all-ceramic systems consist of a ceramic core with a thickness of 0.5 to 1.0 mm and approximately 1.0 to 1.5 mm of space available for veneering ceramic.[19] In the present study, the specimens had ceramic thicknesses of either 0.5, 1 or 1.5 mm, with a core thickness of 1 mm. L* values, which reflects the brightness of the specimens, decreased for both shades as the total thickness of the specimens increased.

The results of the present study are in agreement with previous studies[7,20,25], which showed that the thickness of the layered ceramic influenced the final shade, partially due to the translucency, as the thicker ceramic layers were less translucent.

A previous investigation indicated that a small change in thickness ratio of opaque porcelain to translucent porcelain perceivably influenced the final shade of the specimens. Moreover a* and b* values were increased in all shades as the opaque porcelain thickness was increased. On the other hand, the L* was shade dependent; it was increased in A1 shade specimen and was decreased in both A2 and A3 shades specimens. Hence, a small change in the thickness of opaque porcelain and the translucent porcelain can influence the final shade of the layered porcelain specimen [19]. In addition, it has been concluded that the colour change values increase with the total thickness of the ceramic material and the contributions of core and veneer thickness to the color parameters of the disk specimens were significant[25].

In the present study, the colour of specimens appeared darker, redder and more yellow for A2 specimens, but darker and greener, and less yellow for C2 specimens due to an increase in dentin layer thickness. As the thickness of the body ceramic increased, the effect of diffuse reflection of the core ceramic diminished, and the majority of diffuse reflection occurred in the dentin layer. However, the ΔE value among various thicknesses of ceramic in both shades was above the perceivable level ($\Delta E>1$). Furthermore, these results demonstrated that there were visually detectable colour differences between the different dentin ceramic thicknesses.

Dental ceramics may be fabricated by different laboratory techniques, therefore, resulting in a different distribution of flaws, opportunity for depth of translucency, and accuracy of fit. These differences are significant to the clinician because they persist beyond the walls of the dental laboratory and affect the clinical performance of the restorations[4]. Powder condensation is the conventional technique of forming ceramic restorations, which involves applying a moist porcelain powder with an artist's brush, and then removing the excess water to approximate the powder particles and decrease the porosity. The porcelain is further condensed by viscous flow of the glassy component during firing under vacuum. Powder condensation results in a large amount of residual porosity. The crystalline particles that give the strength for the dental porcelain in the microscopic level are separated by the glassy phase. Hence, this method results in moderately low strength and a wide variation in strength. On the other hand, they have greater translucency than can be achieved by other methods, so this method is used for aesthetic veneer layers on stronger cores and frameworks[41,42].

Although significant differences were observed in L*a*b* parameters, the magnitude of mean colour differences caused by various dentin thicknesses and repeated firings for both veneering-ceramic shades were at a clinically acceptable perception level, except for the 0.5 mm-thick specimens. Therefore, the optimum optical properties of this material can be achieved when the veneering porcelain thickness is 1 mm or more.

CONCLUSIONS

Within the limitations of this study it can be concluded that:

1. Repeated firing of lithium disilicate ceramic (IPS e.max Press) and changes in the thickness of layering porcelain (0.5, 1.0, or 1.5mm) have an effect on the final shade of the two shades (A2 or C2) that were used.
2. The mean ΔE value between the 0.5 and 1.5 mm thickness specimens of dentine ceramic in both shades was above the clinically perceivable level ($\Delta E>3.7$).
3. Clinically, the preparation should provide at least 1 mm thickness for the dentine porcelain, when using this all-ceramic material, to get a relatively stable shade match regardless the number of firings and the shade that is used.

ACKNOWLEDGMENT

This study was funded by Department of Scientific Research at Jordan University of Science and Technology, Irbid-Jordan.

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