The effect of ceramic thickness and number of firings on the color of ceramic systems: An in vitro study

Bulent Uludag, DDS, PhD,[a] Aslihan Usumez, DDS, PhD,[b] Volkan Sahin, DDS, PhD,[c] Kursat Eser, DDS, PhD,[d] and Ertugrul Ercoban, DDS, PhD[e]
Faculty of Dentistry, Ankara University, Ankara, Turkey; Faculty of Dentistry, Selcuk University, Konya, Turkey; Gulhane Military Medical Academy, Dental Unit, Ankara, Turkey

Statement of problem. Although all-ceramic restorations are widely used, there is a lack of information on how color is affected by fabrication procedures. Color matching problems may be encountered in a definitive restoration despite careful shade selection.

Purpose. The aim of this study was to evaluate the effect of dentin ceramic thickness and repeated firings on the color of glass-infiltrated aluminum-oxide (In-Ceram) and leucite-reinforced (IPS Empress) all-ceramic systems using a colorimeter.

Material and methods. Twenty-one disc-shaped specimens, 10 mm in diameter with a 0.6-mm core thickness and 0.5-, 1-, or 1.5-mm dentin ceramic thickness, were made from each of 2 ceramic systems (n=7) . Repeated firings were performed for each group, and the color differences were compared with the color after the initial firing. Color differences among ceramic specimens were measured using a colorimeter (XL-20 Colorimeter), and data were expressed in Commission Internationale d'Eclairage (CIE) LAB system coordinates. Repeated-measures analysis of variance was used to analyze the data (number of firings, ceramic brand, and ceramic thickness) for significant differences. The Tukey honestly significant difference test and paired 2-tailed tests were used to perform multiple comparisons (α=.05).

Results. The L*a*b* values of ceramic systems were affected by the number of firings (3, 5, or 7) ($P<.01$) and ceramic brand (In-ceram or IPS Empress) ($P<.01$). L* and a* values were affected by ceramic thickness (0.5, 1, or 1.5 mm) ($P<.01$); however, b* value was not affected by ceramic thickness ($P=.075$). Significant interactions were present in L*, a*, b* values between number of firings and ceramic brand ($P<.01$), and between ceramic brand and ceramic thickness ($P<.05$). Significant interactions were present between number of firings and ceramic thickness ($P<.01$) in L* and b* values but not in the a* value ($P=.379$).

Conclusion. The analysis revealed that there were substantial changes in L*a*b* color data as the number of firings increased, which resulted in perceptual color changes in L*a*b* color parameters. (J Prosthet Dent 2007;97:25-31.)

CLINICAL IMPLICATIONS

The results of this in vitro study suggest that dentin ceramic thickness and repeated firings of the all-ceramic materials tested are important factors for the color of definitive restorations and should be considered during shade selection and fabrication.

Color matching between ceramic restorations and natural teeth has been a major challenge in dentistry.[1] A dentist is commonly satisfied with the selection of a shade; however, the completed restoration frequently does not match the shade guide, as the esthetic appearance of many ceramics is affected by translucency.[2] Clinically, it is important that ceramic restorations reproduce the translucency and color of the natural teeth.[3] There are many components affecting the match, such as translucency, opalescence, fluorescence, surface texture, and shape.[3] Many ceramic systems have layered veneer porcelains for esthetics because the relatively opaque core materials contribute to the overall color of the restoration.[4] Controlling the ultimate translucency of the core and veneer system is important for achieving the desired esthetic result. Translucency is the relative amount of light transmission or diffuse reflectance from a substrate surface through a turbid medium.[5] Ceramic translucency can be affected by many factors, including thickness,[6,7] microstructure,[8] and the number of firing cycles.[9]

Dentin constitutes the bulk of a tooth and is largely responsible for its color.[1] The color in a natural tooth

[a]Professor, Department of Prosthodontics, Faculty of Dentistry, Ankara University.
[b]Associate Professor, Department of Prosthodontics, Faculty of Dentistry, Selcuk University.
[c]Research Fellow, Department of Prosthodontics, Faculty of Dentistry, Ankara University.
[d]Associate Professor, Department of Prosthodontics, Gulhane Military Medical Academy, Dental Unit.
[e]Private practice, Ankara, Turkey.

occurs from the light directly reflected from the dentin, which has already experienced some internal reflection.[1,10] The popularity of metal-ceramic restorations is largely due to the predictable strength achieved with reasonable esthetics. The esthetic appearance of a metal-ceramic restoration is related to the margin design (porcelain butt margin with a vertical cut back), the alloy used, and the skill of the ceramist.[11] The disadvantage of such restorations is increased light reflectivity because of the opaque porcelain needed to mask the metal substrate.[1] The double-layer color effects in metal-ceramic restorations have been described by O'Brien et al[11,12] based on the Kubelka-Munk equation. Color differences between opaque and dentin layers have been reported as being at least 6.76 ΔE units in the Commission Internationale d'Eclairage (CIE) LAB system.[12] All-ceramic materials offer an esthetic advantage,[9] and some all-ceramic core materials have high in vitro strength values.[13] However, an increase in crystalline content to achieve greater strength generally results in greater opacity.[14]

Instrumental measurements can quantify color and allow communication to be more uniform and precise. Development of more advanced computerized colorimeters and spectrophotometers has increased their use in dental research.[15] Information on these instruments and other color measuring devices exists in the literature.[16] In dentistry, results of a colorimetric device can be altered because the standardized illuminating light emitted from the device can be scattered, absorbed, transmitted, reflected, and even displaced in a sideways direction as a result of the translucent optical properties of teeth and dental ceramics.[17] Seghi et al[18] concluded that data collected by a colorimeter can be significantly altered by the translucency of the ceramics. Haywood et al[19] indicate that colorimeters are designed for flat surfaces, rather than the curved, translucent surfaces found on teeth.

Spectrophotometers measure the reflectance or transmittance factors of an object one wavelength at a time. They have been used to measure the spectral curves of porcelains and extracted teeth.[10,20] However, widespread use of spectrophotometers in dental research and clinical settings has been hindered by the fact that the equipment is complex and expensive and, more importantly, that it is difficult to measure the color of teeth in vivo with these instruments.[10]

Visual color assessments are the result of physiological and psychological responses to radiant-energy stimulation.[15] Alterations in perception are possible from numerous uncontrolled factors. The use of colorimetric measurements provides interpretation of subjective evaluations related to perception of color as physical values.[15] The color difference value (ΔE) represents the numerical distance between L*a*b* coordinates of 2 colors. When the ΔE value of 2 colors is less than 1 unit (ΔE<1), a color match between 2 colors can be judged. When measured color differences are within the 1 to 2 ΔE unit range, correct judgments are made frequently by observers. When ΔE values are greater than 2 ΔE units, all observers can apparently detect color difference between 2 colors.[15] The clinically acceptable limit of color difference value is considered to be 3.7 ΔE units.[15,21]

Ceramists or manufacturers contend that porcelain manipulative variables cause shade variability. Several factors that affect the ability of a ceramic system to produce an acceptable match with corresponding shade guides, such as condensation techniques,[22] firing temperatures,[23] and dentin thickness,[24-26] have been investigated. The effect of dentin thickness on the color of metal-ceramics was studied, and the authors reported that a clinically acceptable shade match was influenced by this parameter.[24] Studies examining color changes of surface colorants after firing have demonstrated pigment breakdown at firing temperatures.[27-29] Hue and value color parameters of metal-ceramic specimens, which were fired 1.6°C and 21°C above the manufacturer's recommended firing temperature, indicated substantial differences.[30] In visual studies of multiple firing of porcelain, color changes were not reported.[31,32] However, O'Brien et al[22] determined perceivable differences (ΔE=1) between the color of ceramic specimens that were fired 3 and 6 times.

The purpose of this study was to evaluate the effects of various dentin ceramic thicknesses (0.5, 1, or 1.5 mm) and number of firings (3, 5, or 7) on the color of glass-infiltrated aluminum-oxide and leucite-reinforced glass ceramic all-ceramic systems. The research hypothesis was that color difference would be noted relative to firing times and dentin ceramic thickness.

MATERIAL AND METHODS

Twenty-one disc-shaped specimens (10 mm in diameter with a 0.6-mm core thickness and 0.5, 1, or 1.5-mm dentin thickness) were made from glass-infiltrated aluminum-oxide (In-Ceram; VITA Zahnfabrik, Bad Sackingen, Germany) and leucite-reinforced glass ceramic (IPS Empress; Ivoclar Vivadent, Schaan, Liechtenstein) all-ceramic systems (n=7). For fabrication of the specimens, the manufacturers' recommendations were followed.

A metal master model (Fig. 1) was used to fabricate aluminum-oxide core specimens. Impressions of the metal master model were made with the putty/wash technique using vinyl polysiloxane (Zetaplus; Zhermack Spa, Badia Polesine, Rovigo, Italy), and impressions were poured with In-Ceram Special Plaster (VITA Zahnfabrik). A fine-grained (2-5 μm) aluminum-oxide slip was brushed on these duplicate plaster models, and the cores were fired in a furnace (InCeramat;

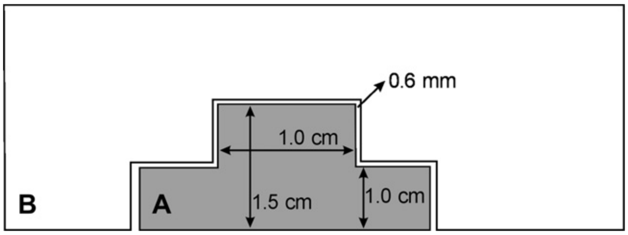

Fig. 1. Mold used to standardize core thickness of In-Ceram specimens. **A,** Metal index for preparation of In-Ceram core material. **B,** Metal index for standardization of thickness of core material.

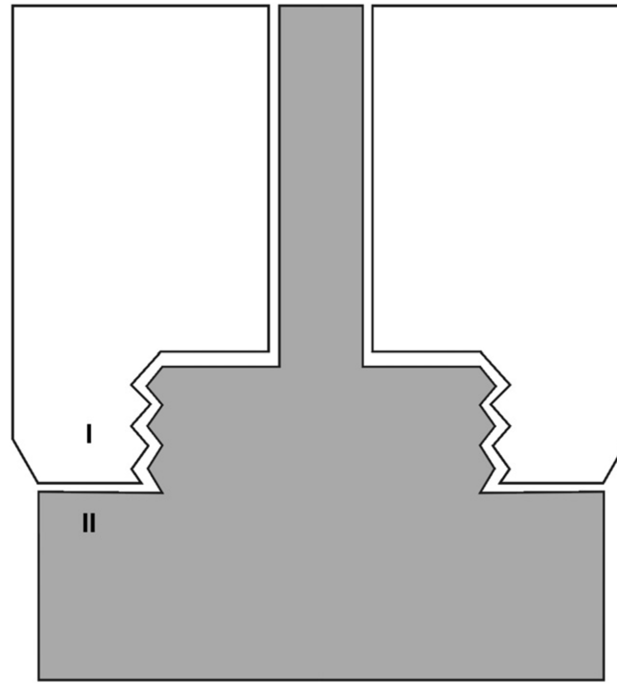

Fig. 2. Apparatus used to standardize dentin ceramic thickness. *I*, First piece of mold with 10-mm cylindrical cavity in middle; *II*, second piece of mold with piston system that moves up and down in cavity when piece is turned.

VITA Zahnfabrik) at 1120°C. Shade A2 of In-Ceram glass powder was mixed with deionized water, applied to the cores, and fired at 1100°C for 6 hours. After infiltration firing, excess glass was removed by airborne-particle abrasion with 50-μm alumina powder (Korox 50; BEGO, Bremen, Germany). Conventional veneering ceramic (Vitadur; VITA Zahnfabrik) was applied on the glass-infiltrated cores with thicknesses of 0.5, 1, or 1.5 mm. A custom-made plastic mold was used to prepare standardized dentin thicknesses (Fig. 2). The apparatus, which used molds similar to those described by others,[30,31,24] was modified for the current study. The mold was prepared in 2 pieces. The first piece (I) had a 10-mm-diameter cylindrical cavity in the middle. The second piece (II) had a piston that was adjusted to the first piece with a screw system so that it could rise and descend in the cavity. The upper surface of the apparatus was divided into 20 equal units. When it was calibrated, the piston moved downward with a sensitivity of 0.05 mm with 1 unit turn of the lower piece. The piston descended 1.0 mm with 20 turns of the screwed lower piece. The required ceramic thickness was provided by adjusting the depth of the cavity above the piston by turning the screwed lower piece the necessary amount. Later, the cavity was filled with ceramic material, and the thickness of the ceramic to be transferred to the core was adjusted in the same manner.

The wax patterns for the leucite-reinforced specimens were made 10 mm in diameter and 0.6 mm in thickness, invested in a phosphate-bonded investment (IPS Empress; Ivoclar Vivadent) using a crucible provided by the manufacturer, and burned out in a furnace (Vita Vacumat 300; VITA Zahnfabrik) at 850°C. The specimens were heat pressed (IPS Empress EP 500 Pressing Furnace; Ivoclar Vivadent) at 1150°C and 5-bar pressure. The muffle was removed from the furnace after pressing, and the investment was air cooled. The specimens were divested using airborne-particle abrasion with 50-μm glass beads (Korox; BEGO). To make the specimens as described for the In-Ceram specimens, the cores were veneered with A2 (from the Vita Shade Guide) dentin ceramic (Ivoclar Vivadent) with the use of the previously mentioned apparatus, which allowed standardization of dentin thickness. The thickness of each group of specimens was then measured with a micrometer (Renfert GmbH, Hilzingen, Germany) with an accuracy of 0.05 mm, and corrected with diamond rotary cutting instruments (863-204-016; Brasseler GmbH & CO KG, Lemgo, Germany) until the desired thickness of dentin ceramic was achieved (0.5, 1, or 1.5 mm).

The color of each specimen was measured with a colorimeter (XL-20 Colorimeter; Gardner Instruments Laboratory Inc, Bethesda, Md). In this system, the specimen was exposed to an emission of light, and reflected light was analyzed with a spectrophotometer. All measurements were recorded in CIELAB coordinates and transferred to a personal computer (Toshiba Americana, Irvine, Calif) for analysis. The instrument calibration was evaluated after measurement of each group (n=7) and recalibrated.

The CIELAB measurements make it possible to evaluate the quantity of perceptible color changes in each specimen. The CIELAB color space is a uniform 3-dimensional color order system. Equal changes in any of the 3 coordinates can be perceived as visually similar. Total color differences were calculated with the following equation[33]:

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

The L* coordinate is a measure of the lightness-darkness of the specimen. The greater the L*, the lighter the

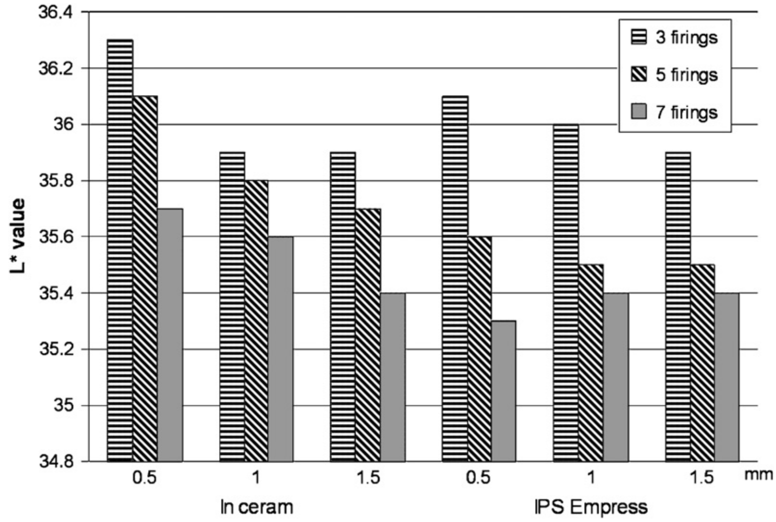

Fig. 3. Mean values of L* for different ceramic thicknesses and brands.

Table I. Multivariate test results based on 3-factor repeated-measures ANOVA for changes in color coordinates after repeated firings of ceramic

Parameter	Effect	Pillai's value	Numerator (df)	Denominator (df)	F	*P*
ΔL*	Number of firings	0.937[a]	2.00	35.00	259.18	<.001
	Number of firings × Brand	0.392[a]	2.00	35.00	11.30	<.001
	Number of firings × Thickness	0.487	4.00	72.00	5.80	<.001
	Number of firings × Brand × Thickness	0.098	4.00	72.00	.923	<.001
Δa*	Number of firings	0.942[a]	2.00	35.00	285.07	<.001
	Number of firings × Brand	0.600[a]	2.00	35.00	26.25	<.001
	Number of firings × Thickness	0.146	4.00	72.00	1.42	.236
	Number of firings × Brand × Thickness	0.503	4.00	72.00	6.045	<.001
Δb*	Number of firings	0.984[a]	2.00	35.00	1046.24	<.001
	Number of firings × Brand	0.882[a]	2.00	35.00	131.31	<.001
	Number of firings × Thickness	0.892	4.00	72.00	14.50	<.001
	Number of firings × Brand × Thickness	0.811	4.00	72.00	12.28	<.001

P<.05 indicates significant difference.
df, Degrees of freedom.
[a]Exact statistics.

specimen. The a* coordinate is a measure of the chroma along the red-green axis. A positive a* relates to the amount of redness, and a negative a* relates to the greenness of a specimen. The b* coordinate is a measure of the chroma along the yellow-blue axis—that is, a positive b* relates to the amount of yellowness; a negative b* relates to the amount of blueness of the specimen. Delta L*, Δa*, and Δb* represent the differences in CIE color-space parameters of the 2 colors.[33]

The results of testing were analyzed with statistical software (SPSS PC, Vers.10.0; SPSS, Chicago, Ill). Repeated-measures analysis of variance (ANOVA) was used to analyze the data (number of firings, ceramic brand, 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).

RESULTS

The results of the ANOVA of L*a*b* color parameters of various thicknesses for the 2 all-ceramic systems are listed in Table I. The L*a*b* values of the ceramic systems were affected by the number of firings (3, 5, or 7 firings) (*P*<.01), ceramic brand (In-Ceram or IPS Empress) (*P*<.01), and ceramic thickness (0.5, 1, or 1.5 mm) (*P*<.01). Significant interactions were present in L*a*b* values between the number of firings and ceramic brand (*P*<.01) and between ceramic brand and ceramic thickness (*P*<.01). Significant interactions

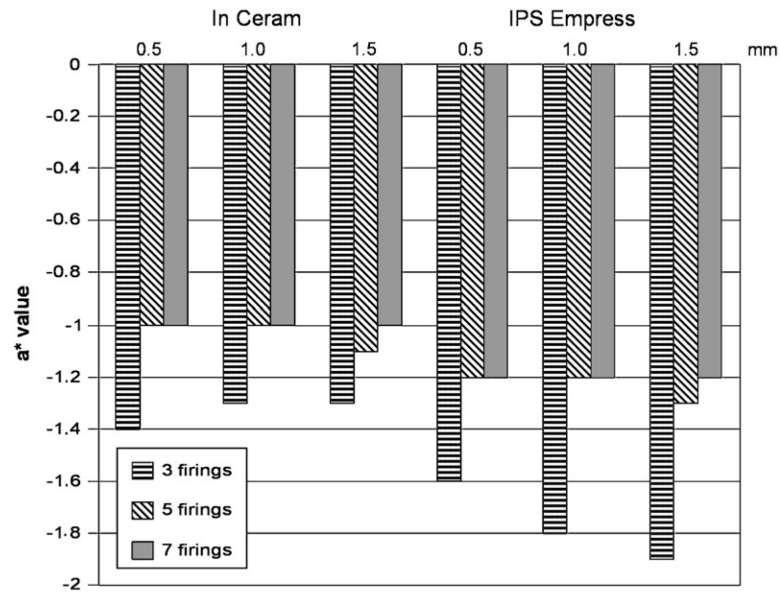

Fig. 4. Mean values of a* for different ceramic thicknesses and brands.

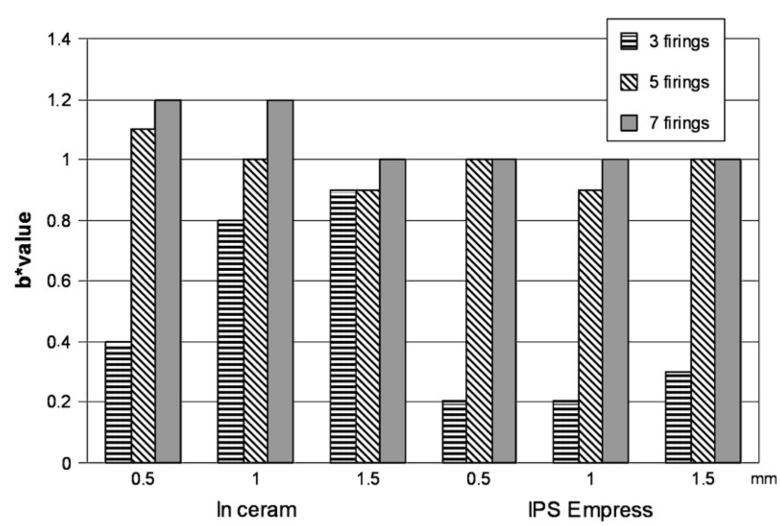

Fig. 5. Mean values of b* for different ceramic thicknesses and brands.

were present between number of firings and ceramic thickness ($P<.01$) for L* and b* values, but not for the a* value ($P=.379$).

As the ceramic thickness increased, significant reduction in L* values ($P<.01$) and increases in a*and b* ($P<.01$) values were recorded for In-Ceram specimens. For IPS Empress specimens, substantial reductions in L* and a* values ($P<.01$) were observed; however, no significant difference was recorded for b* values ($P=.747$) (Figs. 3 through 5). Calculated mean color difference (ΔE) values were less than 1 ΔE unit in both all-ceramic systems (Table II).

An increase in the number of firings resulted in an appreciable decrease in L* values, which created darker specimens for both all-ceramic systems ($P<.01$). The a* and b* color values increased after repeated firings, which resulted in specimens that were redder and more yellow ($P<.01$). The ΔE values were calculated for each specimen within each group (Table III) to determine mean color differences (ΔE), depending on repeated firings. For the In-Ceram specimens, the ΔE value was 1 between 3 or 7 firings, only for 0.5-mm-thick; however, for IPS Empress specimens, the ΔE value was 1 or higher than 1 between 3 to 7 and 3 to 5 firings, for all ceramic thicknesses (0.5, 1, or 1.5 mm).

DISCUSSION

This in vitro study measured the color changes of ceramic specimens prepared at different thicknesses

Table II. Mean ΔE^*_{ab} values of In-Ceram and IPS Empress all-ceramic specimens at different thicknesses after first firing

Ceramic thickness (mm)	ΔE (In-Ceram)	ΔE (IPS Empress)
0.5-1 mm	0.5	0.3
0.5-1.5 mm	0.6	0.5
1-1.5 mm	0.1	0.2

and fired different numbers of times. The results of this study support the hypothesis that color differences would be noted relative to firing times and dentin ceramic thicknesses. There were significant differences in color changes within groups.

The L*a*b* values of ceramic systems were affected by the ceramic brand (In-Ceram or IPS Empress). The leucite-reinforced glass ceramic (IPS Empress) is translucent, whereas the glass-infiltrated alumina coping (In-Ceram) is opaque. Compared to In-Ceram, IPS Empress has a lower crystal content within the matrix, and the relative amount of light transmission from the surface is higher.[7] These differences in optical properties affect the results of the study.

The thickness of the veneering ceramic and coping may be considered in terms of the amount of tooth reduction. It has been reported that an increase in the dentin thickness can cause significant differences in the color of metal ceramics.[12,23] This has been attributed to diffuse reflection properties of the opaque ceramic, which have less effect on color as the dentin ceramic thickness increases. Consequently, it was shown that the shade of metal-ceramic specimens tended to appear darker and more yellow/red because of an increase in the thickness of the dentin.[23]

Thickness of the veneering ceramic is also related to the thickness of the coping. Antonson and Anusavice[6] studied the effect of change in the thickness of ceramics on the contrast ratio of dental core and veneering ceramics and found that the contrast ratio was dependent on the type of ceramic tested. The authors stated that translucency of the layered core/veneering system, as a function of thickness, must also be determined. Heffernan et al [7] studied the influence of core material thickness on its translucency and the influence of core plus ceramic veneer thickness on the overall translucency of the specimens, and concluded that there was a range of ceramic core translucency at clinically relevant core thicknesses. The present study confirms that the thickness of the layered ceramic can influence the overall shade.

In the current study, the color of specimens appeared darker, redder, and more yellow for In-Ceram specimens, but darker and greener for IPS Empress specimens due to an increase in dentin 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

Table III. Mean ΔE^*_{ab} values of In-Ceram and IPS Empress all-ceramic specimens at different thicknesses

Number of firings	ΔE (0.5 mm)	ΔE (1 mm)	ΔE (1.5 mm)
IPS Empress specimens			
3-5	1.0	1.0	1.0
5-7	0.3	0.1	0.2
3-7	1.2	1.3	1.2
In-Ceram specimens			
3-5	0.8	0.4	0.3
5-7	0.4	0.3	0.3
3-7	1.0	0.7	0.5

of ceramic in both systems was below the perceivable level ($\Delta E<1$). Furthermore, these results demonstrated that there were visually undetectable color differences between the core and dentin ceramic.

Although studies[21,31] have demonstrated the minimal effect of repeated firings on the color of body ceramic, O'Brien et al[12] reported that firing ceramic specimens up to 6 times resulted in perceptual color changes. 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 ΔE value after repeated firings was undetectable for the In-Ceram specimens ($\Delta E<1$), except for the 0.5-mm-thick specimens fired 7 times, and just at perceivable levels for the IPS Empress specimens. Conversely, statistically analyzed L*a*b* color parameters showed significant differences with repeated firings. An increase in the number of firings resulted in an appreciable decrease in L* values, which created darker specimens for both all-ceramic systems. It was observed that a* and b* color values increased after repeated firings, resulting in specimens of ceramics that were redder and more yellow. Furthermore, color changes occurred, especially after 5 firings, and less color change was observed with subsequent firings. Color change after repeated firings may also be attributed to the color stability of metal oxides during firing. Several studies[27-29] have suggested that certain metal oxides are not color stable after being subjected to firing temperatures. Crispin et al[27] and Lund and Piotrowski[29] reported that yellow and orange hue stains were the least color stable at the manufacturers' recommended firing temperatures. Mulla and Weiner[28] also indicated that blue was the most unstable stain, while orange demonstrated the greatest color stability at higher firing temperatures. Although significant differences were observed in L*a*b* parameters, the magnitude of mean color differences caused by various dentin thicknesses and repeated firings for both all-ceramic systems were at an acceptable perception level. Clinical success and color stability of ceramic restorations depend on laboratory and clinical variables. Ceramic systems in this study exhibited acceptable visual color changes during firing conditions when

the manufacturers' instructions were followed to ensure esthetically successful restorations.

The present study demonstrated that repeated firings of ceramic and changes in the thickness have an effect on the final shade. However, the study is limited to just 2 ceramic systems (In-Ceram and IPS Empress) and only 1 core thickness (0.6 mm). The condensation technique, which could influence the reproducibility of the disc preparation, was shown to have no influence on the final shade of ceramic.[30-32] Therefore, the shades of sintered layered ceramic and those of assembled ceramic layers were considered equivalent. However, the effects of surface roughness and increase in pore volume on the light transmittance were difficult to control. A future objective is to measure the effects of ceramic thickness and repeated firings of other new ceramic systems with different core thicknesses.

Finally, all-ceramic restorations should be luted to the tooth substrate with a luting agent[21] whose shade and thickness contribute to the definitive appearance of ceramic restorations. Therefore, further studies on the interaction of the ceramic materials with luting agents and other substrates are needed.

CONCLUSION

Within the limitations of this in vitro study, the following conclusions were drawn:

1. The L*a*b* values of ceramic systems were affected by the number of firings (3, 5, or 7) ($P<.01$), ceramic brand (In-Ceram or IPS Empress) ($P<.01$), and ceramic thickness (0.5, 1, or 1.5 mm) ($P<.01$).
2. An increase in the number of firings resulted in an appreciable decrease in L* values, which created darker specimens for both all-ceramic systems. The a* and b* color values increased after repeated firings, which resulted in ceramic specimens that were redder and more yellow.
3. The mean color differences caused by repeated firings were undetectable for In-Ceram specimens ($\Delta E<1$), except for 0.5-mm-thick specimens fired 7 times. However, for IPS Empress specimens, the mean ΔE value was 1 or higher for between 3 to 7 and 3 to 5 firings for all ceramic thicknesses (0.5, 1, or 1.5 mm).

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Reprint request to:
Dr Aslihan Usumez
Selcuk Universitesi
Dishekimligi Fakultesi
Kampus, Konya
TURKEY
Fax: 90-332-2410062
E-mail: asli_u@hotmail.com

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