

Original Article**Effect of Varying Thickness and Number of Coloring Liquid Applications on the Color of Anatomic Contour Monolithic Zirconia Ceramics**Rashin Giti¹, Seyed Ali Hojati²¹ Dept. of Prosthodontics, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran.² Undergraduate Student, Student Research Committee, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran.**KEY WORDS**Thickness;
Prosthesis coloring;
Zirconia;**ABSTRACT****Statement of the Problem:** There is not enough information available about the effect of thickness reduction and the coloring method on the color of new monolithic zirconia ceramic system.**Purpose:** This study aimed to evaluate the effect of varying thickness reductions and number of coloring liquid applications on the final color of anatomic contour monolithic zirconia ceramics.**Materials and Method:** In this experimental *in-vitro* study, 48 disk-shaped monolithic zirconia specimens (10×2mm) were divided into three groups (Group I to III) according to the number of A2-coloring liquid applications (n=16). Each group was then divided into 4 subgroups (n=4) by reducing the thickness of 2 to 0.5 mm in increments of 0.5 mm on the colored surface. Color measurement was done through CIELab (L*, a*, b*) on a reflection spectrophotometer on five different areas of each specimen. Color differences (ΔE) were calculated. Data were analyzed by using two-way ANOVA and Tukey's HSD test ($\alpha=0.05$).**Results:** The number of coloring liquid applications and reducing the thickness of monolithic zirconia disks had significant effects on CIE L* a* and b* values. The CIE L*, a* and b* values increased as the thickness decreased ($p < 0.05$), whereas, increasing the number of coloring liquid applications resulted in decreased CIE L* value and increased CIE a* and b* values ($p < 0.05$).**Conclusion:** Decreasing the thickness of monolithic zirconia increases the lightness and reddish, yellowish appearance. Meanwhile, increasing the number of coloring liquid applications reduces the lightness and makes it seem more reddish and yellowish.**Corresponding Author:** Giti R., Dept. of Prosthodontics, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran. Tel: +98-7136263193-4 Email: giti_ra@sums.ac.irReceived August 2017;
Received in Revised Form October 2017;
Accepted November 2017;Cite this article as: Giti R., Hojati SA. Effect of Varying Thickness and Number of Coloring Liquid Applications on the Color of Anatomic Contour Monolithic Zirconia Ceramics. *J Dent Shiraz Univ Med Sci.*, 2018 December; 19(4): 311-319.**Introduction**

Since the introduction of dental ceramic restorations in 20th century, [1] duplication of natural appearance of teeth has been a major concern in dentistry. What restricted the use of metal-ceramic restorations in high esthetic areas was the light reflection from an opaque porcelain layer, which resulted in an opaque appearance. [2]

Currently, a great portion of esthetically- successf-

ul restorations are made of all-ceramic crowns, which can more accurately match the natural tooth structure in terms of color, surface texture, and translucency. [3] A flawless all-ceramic restoration is quite similar to an unrestored natural tooth. Fixed dental prosthesis are designed and milled as a single-piece zirconia substructure, onto which the veneering porcelain would directly fire. [3]

Some reports have documented chipping, fracture,

breakage, and delamination, resulting in compromised restoration. [4-5] Recently, full contour monolithic zirconia crowns have become popular to overcome the flaws of veneering on zirconia coping. They are considered better due to their great flexural strength, excellent tooth color, and minimal wear on opposing teeth, conservative tooth preparation, durability, improved esthetic, and potential for excellent long-term clinical success. [4]

A recent clinical trial reported that elimination of veneered porcelain on posterior zirconia crowns and fixed dental prostheses yielded esthetically acceptable results. That study included several technical procedures, such as the application of coloring liquids on the pre-sintered zirconia block, surface characterizations, glazing, and polishing of zirconia restorations in order to mimic natural tooth color. [6] What makes zirconia a popular biomaterial is its mechanical strength, chemical and dimensional stability, and the elastic modulus similar to stainless steel. [7]

Zirconia coloring is done through two major techniques, one of which is high temperature sintering only after combining various metal oxides and Y-TZP powder. In the other method, sintering is done after the machined restorations are immersed in chloride solutions of rare earth elements. [8-9] The final shade is affected by the concentration of the solution; however, the immersion duration has been reported to have no such influence. The translucency of zirconia frameworks are directly affected by the coloring liquids, and indirectly by the coloring technique, which influences the shade intensity. [8]

The color of zirconia-based restorations is affected by some factors such as dental substrate, cement, zirconia core, porcelain veneer, and glaze. [10] Various factors are known to determine the overall color of ceramic restorations including the ceramic thickness, the thickness, and color of luting agent, and the color of underlying tooth structure. [11] Several investigations have been conducted about the effect of core and veneer thicknesses on the overall color and translucency of all-ceramic restorations. [12-15]

Changing the thickness of porcelain layer most probably alters the color and translucency. Wanag *et al.* [12] reported an adverse relation between the thickness of dentin porcelain and the values of L^* , a^* , and b^* ;

however, the direction of color change relied on the components of the ceramic systems. Dikicier *et al.* [16] reported the core thickness and aging as the causes of change in the color and L^* , a^* , b^* and ΔE values of all-ceramic systems. Kim and Kim [17] observed that the number of coloring liquid applications influenced the lightness, opalescence, and yellow chromaticity of monolithic zirconia.

The natural whiteness and opacity of monolithic zirconia allows its coloring to be done before sintering. In clinical occlusal adjustment, the thickness of monolithic zirconia would be possibly decreased. Literature review revealed the lack of enough studies about the effect of coloring technique and different thicknesses of monolithic zirconia on the overall color of this type of all-ceramic restoration. Therefore, this study aimed to evaluate the effect of varying thickness reductions and number of coloring liquid applications on the final color of anatomic contour monolithic zirconia ceramics. The null hypothesis was that there would be no significant difference in color among the monolithic zirconia ceramics with different degrees of thickness reduction and increase in the number of application of coloring liquid.

Materials and Method

In this experimental study, 48 disk-shaped specimens (2×10 mm) (Figure 1) from monolithic zirconia blocks (Lot No:120555; Whitepeaks Dental, Germany) were colored with coloring liquid (Lot No.: 40127, 40129; Tanaka ZirColor, A2, Tanaka Dental, Skokie, IL, USA). The coloring liquid was applied with a brush (2850-B; Babara, Kobe, Japan) according to the manufacturer's recommendations.

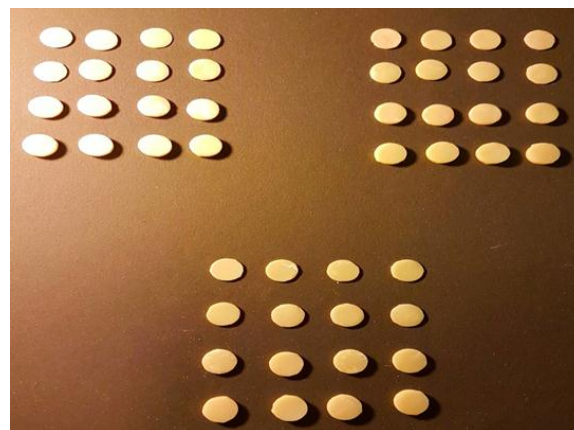


Figure 1: Forty-eight disk-shaped specimens (2×10 mm) made of monolithic zirconia

The specimens were divided into 3 groups (n=16 per group) according to the number of coloring liquid applications, Group 1: once, Group 2: twice, and Group 3: three times (Figures 2-4). The specimens were heated in a furnace (Austromat baSiC; Dekema Dental-Keramiköfen GmbH, Freilassing, Germany) with a step sintering procedure; sintering at 950 °C for 10 minutes, and at 1500 °C for 2 hours.

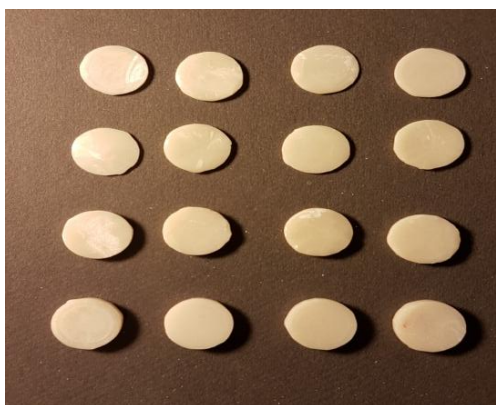


Figure 2: Group 1: Zirconia disks colored with A2 coloring liquid applied once



Figure 3: Group 2: Zirconia disks colored with A2 coloring liquid applied twice



Figure 4: Group 3: Zirconia disks colored with A2 coloring liquid applied three times

After sintering, the thickness adjustment was performed as done in Kim and Kim's study. [18] The grinding procedure was performed by the horizontal grinding machine (HRG-150, AM Technology, Asan, Korea). The final dimensions of the specimens were 10×2.0mm. The final thickness was checked with a digital height gauge (Digimicro ME-50HA; Nikon Corp., Tokyo, Japan) with the accuracy of 1 µm on five different sites of each specimen (center and each corner).

Each group was then subdivided into four subgroups (n=4) by reducing the thickness of 2 to 0.05 mm in increments of 0.5-mm on the colored surface by using a horizontal grinding machine; Subgroup 1 (2mm), Subgroup 2 (1.5mm), Subgroup 3 (1mm) and Subgroup 4 (0.5 mm).

Color parameters were obtained from CIE-Lab (Commission Internationale de l'Eclairage L*, a*, b*) color space relative to D65 on a reflection spectrophotometer (CM-3500d; Konica Minolta, Tokyo, Japan). The color difference was determined by comparing the average CIE values against a white background. The spectrophotometer was calibrated with a white ceramic. The color difference between each subgroup was calculated by using CIE Lab color-difference formula denoted by $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$, where ΔL^* , Δa^* , and Δb^* referred to the differences in lightness, red/green axis, and yellow/blue axis, respectively.

All measurements were made at the center and each quarter of the specimen, the values were averaged. Statistical analyses were performed by using SPSS software (version 20.0; SPSS Inc., Chicago, IL, USA) with α level set at 0.05. To find any significant difference in color values among the subgroups, two-way ANOVA was carried out followed by Tukey's HSD test.

Results

The means and standard deviations (mean±SD) of the L*, a*, and b* values in the CIELab color system are presented in Tables 1, 2, and 3, respectively. Based on the results of this study, the CIE L* value was significantly affected by the number of coloring liquid applications ($p= 0.034$) and the thickness reduction of the monolithic zirconia disks ($p= 0.0$). Accordingly, increasing the number of coloring liquid applications resulted in significant reduction of CIE L* value. Moreover, reducing the thickness from 1.5 to 1 mm, and from

1 to 0.5 mm increased the CIE L* value ($p < 0.05$). Reducing the thickness from 2 to 1.5 mm increased the CIE L* value; however, the difference was not statistically significant.

The results also showed that the CIE a* value was significantly influenced by the number of application of coloring liquid ($p = 0.0$) and the thickness reduction of monolithic zirconia disks ($p = 0.001$). In fact, increasing the application times of coloring liquid from once to twice, and one to three times resulted in significant increase of the CIE a* value ($p < 0.05$). Moreover, decreasing the thickness from 2 to 1 mm and from 2 to 0.5 mm significantly increased a* value ($p < 0.05$).

Table 1: The mean (standard deviation) of CIE L* values of each group as a function of thickness reduction

Thickness (mm)	Number of coloring liquid applications		
	Once	Twice	Three times
2	75.82 (1.21)	74.62 (0.49)	73.62 (0.71)
1.5	76.65 (0.93)	75.47 (0.52)	75.1 (0.28)
1	81.62 (2.08)	82.00 (0.31)	79.87 (1.45)
0.5	84.12 (0.75)	82.1 (0.66)	84.65 (3.37)

Table 2: The mean (SD) of CIE a* values of each group as a function of the amount of thickness reduction

Thickness (mm)	Number of coloring liquid applications		
	Once	Twice	Three times
2	5.47 (0.92)	7.47 (1.50)	7.47 (1.03)
1.5	6.80 (0.39)	7.82 (1.32)	8.40 (1.16)
1	7.75 (1.50)	8.92 (0.70)	8.20 (0.86)
0.5	6.72 (0.25)	10.42 (0.5)	8.45 (0.51)

Table 3: The mean (SD) of CIE b* values of each group as a function of the amount of thickness reduction

Thickness (mm)	Number of coloring liquid applications		
	Once	Twice	Three times
2	34.90 (2.44)	36.15 (0.58)	37.10 (0.53)
1.5	37.35 (1.20)	36.72 (0.70)	39.25 (0.23)
1	39.55 (0.98)	41.12 (1.20)	41.57 (0.41)
0.5	38.02 (1.35)	37.45 (2.79)	42.02 (1.35)

The present findings also showed the CIE b* value to be significantly affected by the application times of coloring liquid ($p = 0.00$) and reduction of the thickness of monolithic zirconia disks ($p = 0.00$). By increasing the application times of coloring liquid from one to three times and from twice to three times, this value was increased ($p < 0.05$). Besides, decreasing the thickness from 2 to 1.5mm and from 1.5 to 1mm, the b* value increased ($p < 0.05$). Nevertheless, changing the thickness from 1 to 0.5mm led to a decreased CIE b* value ($p < 0.05$).

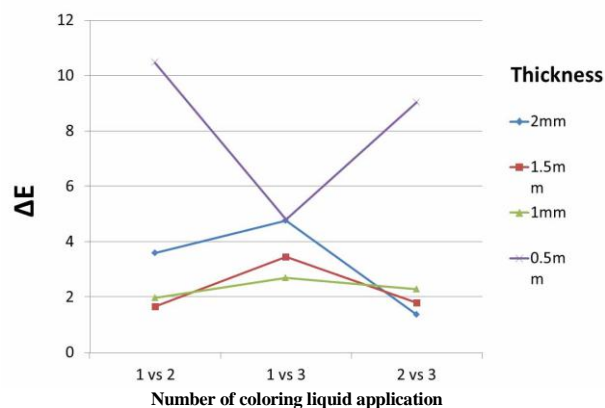


Figure 5: The color differences (ΔE) among the groups in each subgroup

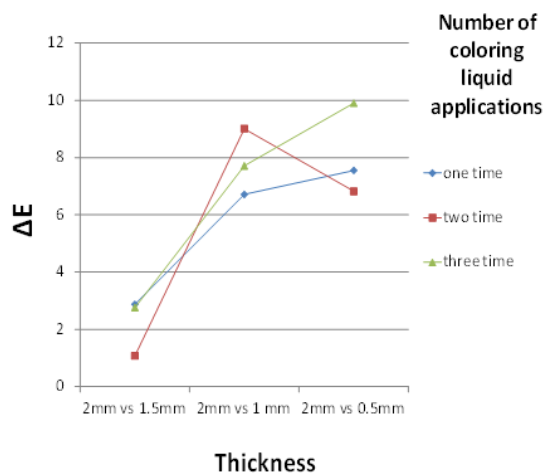


Figure 6: The color differences (ΔE) among the subgroups in each group

Figures 5 and 6 displays the color differences (ΔE) present between the subgroups. Interpretation of the color difference in this study was based on the visual matching study of Johnston and Kao [19] who announced that color difference of (ΔE) 3.7 units to be clinically acceptable in resin composites. We detected clinically-perceptible color changes ($\Delta E > 3.7$) in decreasing the thicknesses from 2 to 1mm and from 2 to 0.5mm, and in once, twice, and three times application of coloring liquid. However, reducing the thickness of specimens from 2 to 1.5mm did not caused detectable color changes ($\Delta E < 3.7$) (Figure 6).

Clinically perceptible color differences ($\Delta E > 3.7$) were observed as the result of increasing the application times of coloring liquid from once to twice and from one to three times 2-mm thick specimens. However, in 1.5 and 1 mm thicknesses, increasing the application times of coloring liquid from once to twice, twice to three times, and once to three times did not clinically

affect the resulting color ($\Delta E < 3.7$). Whereas, in 0.5-mm thick specimens, increasing the application times of coloring liquid from once to twice, twice to three times, and once to three times caused perceptible color changes in monolithic zirconia ($\Delta E > 3.7$) (Figure 5).

Discussion

This study surveyed the effects of various changes in thickness reductions and number of coloring liquid applications on monolithic zirconia. According to the results, the null hypothesis was rejected because there were significant differences in L^* , a^* , and b^* parameters between the monolithic zirconia specimens with different thickness reductions and different numbers of coloring liquid application. Based on the results of this study, reducing the thickness of zirconia specimens significantly increased the CIE L^* , a^* and b^* values.

Different studies investigated the effect of various changes in thickness of core and veneer on the final shade of metal ceramic restorations. [20-24] Douglas and Przybylska [20] reported substantial increase of L^* value as the result of decreasing the porcelain thickness. It was observed that the pattern of color changes depended on the porcelain shade and type of porcelain fused to metal (PFM) alloy. They discussed that increasing the dentin porcelain thickness enhanced the scattering and absorption of incident light and decreased the light reflected from the opaque layer. It was the reason for increased L^* value by decreasing the thickness of porcelain in PFM restorations. [20]

Regarding the all-ceramic systems, Shokry *et al.* [25] and Dozic *et al.* [26] showed that L^* value generally decreased due to the increased absorption of incident light in the thicker all-ceramic restorations. Douglas and Przybylska [20] reported that changing the opacity of all-ceramic system core affected the light reflection at the opaque core. They observed that decreasing the porcelain thickness had less effect on the semi-translucent all-ceramic restorations. The result of the present study was in line with the above-mentioned studies, which showed that reducing the thickness of monolithic zirconia could substantially increase the value of this restoration. This might be related to the higher incident light reflection and lower absorption of incident light from the thinner specimens.

On the other hand, Kim *et al.* [18] showed that the

changes in L^* parameter of monolithic zirconia were different from those in metal-ceramic or all-ceramic restorations. They reported a significant decrease in L^* value at the initial 0.1-mm thickness reduction; but, no further significant changes were observed in this parameter with more thickness reductions. This was suggested to be related to the polycrystalline monolayer structure of monolithic zirconia, which does not have any veneering porcelain. The first 0.1-mm thickness reduction might have reduced the scattering, which caused lower L^* value. However, as the thickness reduction proceeded, monolithic zirconia could act as an opaque core and induced internal reflection. Hence, they concluded that the reduced reflection could compensate for the increased internal reflection and kept the L^* value stable. [18]

Another study showed that increasing the thickness of ceramic veneer from 1 to 1.5mm, resulted in decreased L^* value and increased a^* and b^* values. [27] Likewise, Dozic *et al.* [26] reported an inverse relationship between the ceramic thickness and translucency, which could affect the final shade of all-ceramic crown. Son *et al.* [28] demonstrated that CIE L^* value decreased as the veneer porcelain thickness increased from 0 to 2mm.

Regarding the chromatic parameters of a^* and b^* which indicate the red-green and yellow-blue axis, respectively, the present study reported increase of a^* value by reducing the thickness of monolithic zirconia from 2 up to 0.5mm. Moreover, b^* value increased in the first two 0.5mm thickness reductions from 2 up to 1mm. However, decreasing the thickness from 1 to 0.5mm resulted in decreased b^* value, although, this reduction was less significant than the first two increasing of this parameter. Notably, the CIE a^* value changed gradually as the thickness of monolithic zirconia decreased; whereas, the changes in CIE b^* values occurred more significantly than a^* parameter when the zirconia specimens were thin. The differences might be due to the wavelength-dependent color characteristics.

A study on body porcelain announced that the scattering coefficients were higher at shorter wavelengths in the visible radiation range. [28] Other investigations reported that thickness-dependent reflectance changes were significantly greater at shorter wavelength (400 nm) than at longer wavelengths (500, 600, and 700 nm). [29-30] In the human visual system, shorter wave-

lengths or the Z tristimulus region was correlated with the blue color area as the CIE b^* value indicates the yellow-blue coordinates.

The current study used a standard white background to minimize the influence of background on the measured color. Our result in relation to the a^* parameter was in agreement with what was found by Kim *et al.* [18] who showed that decreasing the thickness of monolithic zirconia led to increase a^* value and a more reddish appearance. Yet, they noted that decreasing the thickness from 2 to 1 mm generally increased the b^* value, which contrasted the present results about the b^* parameter.

Oh and Kim [27] detected a positive relationship between increasing the thickness of zirconia core from 1 to 1.5 mm and a^* and b^* values, which was in contrast with the result of this study. Dikicier *et al.* [16] found that increasing the thickness of core materials rose a^* value and decreased the b^* value. Their specimens appeared more blue/red because of the increased a^* and decreased b^* values. These results was in line with the findings of the present study about the b^* parameter. Douglas *et al.* [31] identified that the observers were more sensitive to color change in redness than yellowness of metal-ceramic crowns.

Shokry *et al.* [25] evaluated the effect of varying core and veneer thickness on the color parameters of IPS Empress and In-Ceram Spinel. They reported that increasing the ceramic thickness reduced the brightness and increased the reddish and yellowish appearance of ceramic. Such different result might be attributed to the different types of ceramics with different translucencies.

Barizon *et al.* [32] reported that the ceramic specimens with 0.3 mm thickness presented higher brightness and a color shift toward green, compared with those of 0.7-mm thickness and no shift was detected on the blue-yellow axis (b^* value). The fraction of incident light that is reflected, absorbed, and transmitted is determined by the thickness of the specimen as well as the scattering and absorption characteristics of the employed material. [33] In another study, the CIE L^* and b^* values generally decreased, while a^* values increased as the core thickness was increased. The specimens appeared more blue/red because of increasing a^* and decreasing b^* values. [16]

Normally, the naked eyes can hardly discern min-

or numerical color differences in dental materials. Previous research on porcelain color change announced the $\Delta E < 1$ as clinically undetectable by the human eye. [33-34] Paul *et al.* [35] reported that the results obtained through spectrophotometry were rather significant compared with visual shade matching. The color differences values (ΔE) were determined based on the changes of L^* , a^* , and b^* values.

Some studies addressed the minimum color difference (ΔE) perceivable by human observers. Seghi *et al.* [36] attributed the alterations in color perception to a number of uncontrolled factors such as fatigue, aging, emotions, lighting conditions, and metamerism; however, human eye-brain combinations could detect minor color differences between two objects. They reported that the observers correctly detected the $\Delta E > 2$ units 100% of the times, and infrequent incorrect judgments were made in cases with $1 < \Delta E < 2$ measured color differences. [36]

Comparing the perceptibility threshold, some researchers reported that the color difference accepted by 50% of observers was 1.7-3.3 ΔE units. [31, 37-38] Presence of intraoral factors causes the clinically perceptible and acceptable color differences to be of greater values compared with the values measured in a strictly controlled *in vitro* environment. [38-39] Many studies tried to determine the threshold for perceptibility and acceptability of color difference. [39-40] Johnston and Kao [19] determined 3.7 ΔE^* units as a perceptibility threshold and 6.8 ΔE^* units as a borderline for color match or mismatch between composite veneers and teeth.

Researchers suggested that the porcelain thickness might have more effect on the perceptible color changes in regions adjacent to the cervical margin of ceramic restorations, where the porcelain is quite close to the core material. If so, changes in porcelain thickness in these areas would cause greater changes in the shade of restoration. [40] Such phenomenon would also make it more difficult for the technicians to predict and match the shade of the final restoration.

The results of this study showed clinically detectable color change ($\Delta E > 3.7$) with decreasing the thickness from 2 to 1mm and from 2 to 0.5mm in once, twice, and three times application of the coloring liquid. It was also found that increasing the application times of coloring liquid would decrease the L^* value and in-

crease a^*/b^* values. However, the impact was only perceptible in the color of specimens with 2 and 0.5 mm thicknesses ($\Delta E > 3.7$), but not in 1- and 1.5-mm-thick zirconia specimens ($\Delta E < 3.7$).

The result of this study conform to those of Kim *et al.* [17] who reported that by increasing the number of coloring liquid applications, the CIE L^* value decreased and CIE b^* value increased. However, they observed no significant difference among the groups regarding a^* value. Therefore, increasing the number of coloring liquid applications produced a darker and more yellowish monolithic zirconia specimen with a single shade of A2. [17]

Cho *et al.* [42] investigated the color and translucency changes of enamel porcelain after repeated staining procedures. The results showed increased lightness and chroma, but decreased translucency. Kim *et al.* [18] observed that applying more coloring liquid resulted in deeper infiltration of the coloring liquid. According to their findings, single application of the coloring liquid infiltrated 0.1mm deep, double application yielded 0.2mm deep infiltration, and triple application resulted in 0.3mm infiltration into the monolithic zirconia specimen.

Among the several potential limitations of this study was the 3-mm aperture diameter of the spectrophotometer for reflectance measurement with possible edge loss, which would have affected the color measurement. Moreover, this study included only the color shade of A2 in a specific kind of monolithic zirconia system and a single coloring liquid. Therefore, further studies are required to evaluate the influence of varied color combinations with different monolithic zirconia systems.

Conclusion

Within the limitations of this study, it can be concluded that decreasing the thickness of monolithic zirconia would increase the lightness of restoration, and would mainly increase the CIE a^* and b^* values. Moreover, increasing the application time of coloring liquid reduces the lightness and makes it look more reddish and yellowish by using A2 coloring liquid.

Acknowledgments

This work was financially supported by Shiraz Univer-

sity of Medical Sciences (Grant#95-01-03-13755). Appreciations are expressed to Mehrdad Vossoughi from the Dental Research Development Center for the statistical analyses.

Conflicts of Interest

Authors declare that there is no conflict of interest.

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