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Effect of different coloring techniques and surface treatment methods on the surface roughness of monolithic zirconia

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ABSTRACT

Background: This study aimed to evaluate the effect of different coloring techniques and surface treatment methods on the surface roughness of monolithic zirconia ceramic.

Materials and Methods: In this *in vitro* study seventy-two disk-shaped monolithic zirconia (2 mm × 10 mm) were divided into three coloring techniques groups (white, internal staining, external staining) (n = 24). Each group was subdivided into four surface treatment subgroups (n = 6), as unpolished, polished with Shofu polishing kit, polished with dental direct polishing kit, and glazed. Profilometer was used to measure the Ra (roughness average) and Rz (roughness height) surface roughness values (μm) and scanning electron microscopy (SEM) for visual inspection of the surface morphology. The surface roughness parameters were calculated and analyzed with two-way ANOVA and Tukey's *post hoc* test (α = 0.05).

Results: The coloring technique, surface treatment method, and interaction of these two parameters significantly affected the Ra and Rz parameters (P < 0.05). Concerning the surface treatment, the Rz value was significantly higher in the unpolished subgroup, followed by the glazed and polished subgroups. However, the two polishing systems were not significantly different. The internal staining group had significantly higher Rz value than the other staining method, when the specimens were glazed or polished with Shofu kit. SEM showed multiple scratches in unpolished samples which were smoothened by glazing and specially by polishing.

Conclusion: Among all the studied surface treatment methods, the lowest surface roughness was observed in highly polished monolithic zirconia, which was even less than the glazed one. The internal staining method can create a rougher surface for some of the surface treatment methods.

Key Words: Ceramic, prosthesis coloring, staining, zirconia

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INTRODUCTION

Of all the available restorations, all-ceramic crowns are among the options that offer the most desirable esthetic outcome. Compared with other restorations, the color and translucency of all-ceramic crowns more easily mimic the natural tooth structure.[1] Clinicians believe that the zirconia-based ceramics are the most preferable choice of all-ceramic systems,[2] as they meet the biomechanical needs such as chemical and dimensional stability, high mechanical strength, and fracture toughness.[3] All-ceramic crowns and fixed dental prostheses (FDPs) have long benefited from the

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highly stable material of yttrium-stabilized tetragonal zirconia polycrystal (Y-TZP) ceramics as the core material. What makes them so favorable is their great strength and superb fracture resistance against the inherent transformation-toughening mechanism.[4]

To meet the esthetics needs, glass ceramic or translucent feldspathic materials are used to veneer the zirconia frameworks. Besides the unclear bonding mechanism between Y-TZP and the veneering ceramic, there is another undeniable weak point to these restorations, which is the core–veneer interface that expose them to the risk of ceramic chipping.[5] Such breakdowns can be due to the incongruent coefficient of thermal expansion between the zirconia and the veneered porcelain. Attempts to overcome these failures led to development of highly sintered monolithic or anatomically contoured zirconia crowns. Zirconia restorations went clinically more successful and reliable as the veneering porcelain layer was excluded.[6]

Sometimes, diamond rotary instruments are used for modification and intraoral adjustment of restorations to achieve optimal occlusal and proximal contacts.[7] Occlusal adjustment might require removing the glazed surface of a ceramic restoration after cementation. Different studies have investigated the effect of various grinding procedures on the surface roughness of different Y-TZP ceramics.[8,9] The findings have shown that the glaze layer is likely to diminish in the first 6 months and so put the underlying zirconia at risk of exposure.[10]

To use solid zirconia restorations safe and effectively, the risk of wear of opposing teeth and dental restorations should be cautiously handled. Polishing the zirconia ceramics highly helps preventing or slowing down wear of the opposing enamel.[10,11] Moreover, polishing is reported to improve the durability and esthetics of restorations by eliminating the defects caused by surface grinding.[12,13] While a smooth restoration surface might exhibit more specular reflection, a rough surface can modify the visual features and light reflection.[13] Another advantage of polishing is the reduced risk of plaque accumulation and periodontal diseases.[12] Sincere glazing should only be done in a dental laboratory with a furnace; multiple office visits are required; meanwhile, repeated firings are likely to destroy the ceramic surface and can trigger phase transformation.[14] Some studies showed that glazing was not only unable to improve the flexural strength but also made it susceptible to low-temperature degradation.[15,16]

Finishing and polishing may be an alternative technique. Huh *et al*.[17] compared the effectiveness of six zirconia polishing systems and detected clinically acceptable results in all systems. According to Bollen *et al*.,[12] a surface roughness (Ra) of <0.2 μm is required for both natural teeth and restorations as the threshold of bacterial accumulation. They believed that polishing and/or reglazing should be performed to smoothen the surface of a ceramic restoration.[12] Generally, all-ceramic restorations are first polished or reglazed, then, cemented. Since after cementation, only polishing is allowed, selecting a suitable polishing system is important.[18]

Profilometer is a device for quantitative measurement of the surface roughness. However, as the instrument scans only some parts, the roughness values are not always definite representative of the actual topography of ceramic surfaces.[19] Thus, scanning electron microscopy (SEM) is also recommended to get more comprehensive results.[13] Finishing and polishing of zirconia restorations can be done via various systems. However, controversy exists about the effects of grinding, polishing, and glazing on the surface roughness and other properties of zirconia.[20]

To get a natural-looking restoration, white zirconia needs to be colored. Among all the methods of coloring the zirconia for dental purposes, three are most commonly used; one is mixing the ZrO2 powder with metal oxides at the production stage to obtain precolored blocks. Another method is presintering infiltration of the green-stage frameworks with specific coloring liquids. The third method is postsintering painting of the zirconia with liners, which needs to be fired in a dental ceramic furnace.[21]

Despite the development and clinical use of numerous ceramics stained by novel methods, data are still limited about their surface roughness.[22] Actually, no study has investigated the effect of different coloring techniques and zirconia polishing systems on the surface roughness of monolithic zirconia. Therefore, the present study was conducted to evaluate the effects of different staining methods and surface finishing procedures on the surface roughness of monolithic zirconia. The null hypotheses were that no difference would be found in the surface roughness among the zirconia groups stained by different coloring methods under the same surface treatment conditions and that the surface roughness of monolithic zirconia stained by the same method would not be influenced by different surface treatment methods.

MATERIALS AND METHODS

In this *in vitro* experimental study, 72 presintered disk-shaped specimens (2 mm × 10 mm) were fabricated from monolithic zirconia blocks (Zircostar, Kerox u. 1., Hungary) using a CAD/CAM system (imes-icore, 34oi, Germany). Forty-eight disks were cut from pure white zirconia blocks and 24 from precolored A2 blocks. All of the disks were abraded with 400-grit wet SiC (silicon carbide) abrasive paper to ensure that the test surfaces were under the same condition.

The samples were divided into three main groups (*n* = 24) according to the employed coloring process. The first group of samples were white zirconia, fully sintered in furnace (MIHM-VOGT, Dental-Geratebau, Germany) at 1450°C in an air environment, for a holding time of 2 h, and allowed to cool down to room temperature. The second was an internal staining group, in which all the precolored zirconia disks were sintered as previously described. The third was an external staining group, in which white zirconia disks were immersed into A2 coloring liquid (Colouring liquid, Kerox, Miskolc, Hungary) for 1 min. The coloring liquid was applied according to the manufacturer's recommendations and dried with an infrared lamp for 30 min. Sintering was done as in the two previous groups.

All the specimens of the three groups were mounted into the center of the brass holders with acrylic resin. Parallelism between the specimens and the surface of the brass holders was maintained during mounting [Figure 1]. Then, each group of specimens were randomly subdivided into four subgroups (*n* = 6 per subgroup) based on the employed surface treatments. The first subgroup was left untreated as the control group. The second subgroup was polished with Shofu zirconia polishing system (CoreMaster, SHOFU, Japan) [Figure 2a]. The two polishers of this system are CoreMaster Coarse (blue black polishers) and CoreMaster Light (white polishers), which is densely filled with pure diamond particles. The third subgroup was polished with Dental Direct zirconia polishing system (Panter, Dental Direct, Germany) [Figure 2b]. The two rubber polishers of

Figure 1: Sample mounted into acrylic resin.

Figure 2: (a) Shofu polishing system, (b) dental direct polishing kit.

this zirconia polishing system were purple and white, the former of which was used for smoothing and the latter for glossing. This system also had the goat hair brushes and diamond polishing paste for achieving the high-gloss effect. Polishing was done using two instruments for each polishing system in one direction with a low speed handpiece (KAVO GENTLEpower LUX 25 LP, KaVo, Biberach, Germany), for 1 min per each polishing instrument (a total of 2 min for each polishing system). Finally, after using the instruments in dental direct polishing system, the diamond polish paste was used for 1 min according to manufacturer's instruction to achieve the high-gloss effect. In each polished subgroup, a new polisher was used for every 5 specimens. The polished specimens were rinsed with air–water spray for 15 s, ultrasonically cleaned (CP360 Powersonic, Crest Ultrasonics, NJ, USA) in distilled water for 1 min, and then, rinsed and dried.

The fourth subgroup was subjected to glaze with A2 color. In this subgroup, the overglaze powder was mixed with the glaze liquid (DDNatureZr, Glasur Glaze, Dental Direct GmbH, Germany) and applied in a thin coat using a ceramic brush as recommended by the manufacturer and then fired at 820°C for 2 min

(Ivoclar Vivadent, Switzerland). Firing programs were set according to the manufacturer's recommendations. Figure 3 displays the arrangement and abbreviations of all the experimental subgroups with different coloring techniques and surface treatment methods.

The mean surface roughness (Ra [μm]) and the arithmetic mean height of the surface profile (Rz [μm]) of specimens were measured with a contact profilometer (Rogosurf 20, TESA, Switzerland) with 0.25 mm cutoff length, 4 mm transverse length, and 0.001 μm resolution. A diamond stylus of 5 μm radius and 90° stylus angle was traversed at a constant speed across each of the specimens with a force of 0.75 mN. To determine the roughness values, the measuring speed was set at 0.5 mm/s, and the reading direction in all cases was perpendicular to the surface of the specimens (90°). Measurements were done three times for each specimen at three different sites perpendicular to the direction of the grinding, and the collective average was obtained. The profilometer was calibrated before measurements in each group. All the profilometer records were made as close as possible to the sample center. The higher the Ra and Rz values were, the rougher the surface would be.

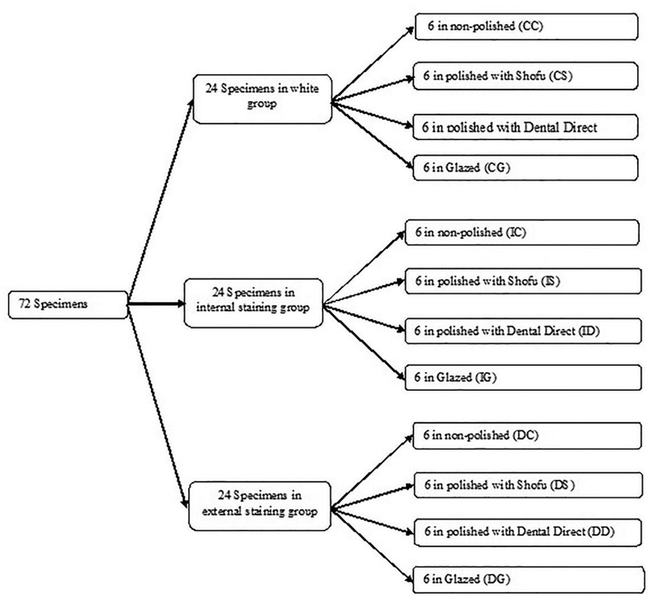

Figure 3: Experimental design.

For the qualitative characterization of the monolithic zirconia specimens, they were removed from the epoxy resin, ultrasonically cleaned in distilled water for 5 min, and then rinsed and dried. The specimens were gold coated with a sputter coater (S150B; Edwards, Crawley, UK) and examined at 15 kV using a scanning electron microscope (JSM-6335 F; JEOL, Tokyo, Japan). For visual inspection and assessment of the surface morphology, SEM photomicrographs were taken at ×500 magnification.

All the calculations and statistical analyses were done with SPSS software (version 13.0, SPSS Inc., Chicago, IL, USA). The mean values and standard deviations were calculated and analyzed using two-way ANOVA and Tukey's *post hoc* test ($\alpha = 0.5$).

RESULTS

The mean and standard deviation of Ra and Rz (μm) values with respect to the coloring techniques and surface treatment methods are displayed in Table 1, as well as Figures 4 and 5, respectively. Table 2 displays the results of two-way ANOVA for Ra and Rz parameters.

The findings showed that the Rz parameter was significantly affected by the coloring technique ($P < 0.001$), surface treatment method ($P < 0.001$), and the interaction of the two parameters ($P < 0.001$). In all the three coloring techniques (white, internal, and external staining), the unpolished subgroup had

Table 1: The mean and standard deviation of Ra and Rz (μm) of all subgroups affected by different surface treatment methods and coloring techniques

Variable	Surface treatment method	Coloring technique		
		White	Internal staining	External staining
Ra	Unpolished	1.01 ± 0.19^{Aa}	$0.89\pm0.36^{A,a,b}$	$0.45\pm0.5^{A,b}$
	Shofu polishing system	$0.1\pm0.01^{C,b}$	$0.21\pm0.04^{B,a}$	$0.08\pm0.01^{A,b}$
	Dental direct polishing system	$0.07\pm0.02^{C,a}$	$0.15\pm0.17^{B,a}$	$0.07\pm0.01^{A,a}$
	Glazing	$0.44\pm0.13^{B,a,b}$	$0.58\pm0.43^{A,B,aBa}$	$0.17\pm0.08^{A,b}$
Rz	Unpolished	$4.7\pm0.61^{A,a}$	$4.25\pm1.4^{A,a}$	$3.54\pm0.61^{A,a}$
	Shofu polishing system	$0.42\pm0.07^{B,C,b}$	$1.15\pm0.21^{C,a}$	$0.31\pm0.08^{C,b}$
	Dental direct polishing system	$0.3\pm0.1^{C,a}$	$0.43\pm0.17^{C,a}$	$0.29\pm0.09^{C,a}$
	Glazing	$0.92\pm0.02^{B,b}$	$2.7\pm1.1^{B,a}$	$0.88\pm0.08^{B,b}$

Different superscript capital letters in each column and lower case letters in each row indicate statistically significantly difference ($P<0.05$)

Table 2: Results of two-way ANOVA for Ra and Rz parameters

Variable	Source	Sum of squares	df	Mean square	*F*	*P*
Ra	Corrected model	7.127	11	0.0648	11.665	0.000
	Intercept	8.969	1	8.969	161.492	0.000
	Coloring technique (A)	0.941	2	0.471	8.473	0.001
	Surface treatment method (B)	5.473	3	1.824	32.846	0.000
	Interactions A×B	0.713	6	0.119	2.139	0.049
	Error	3.332	60	0.056		
	Total	19.428	72			
Rz	Corrected model	183.008	11	16.637	49.424	0.000
	Intercept	197.647	1	197.647	587.153	0.000
	Coloring technique (A)	9.372	2	4.686	13.921	0.000
	Surface treatment method (B)	163.656	3	54.552	162.059	0.000
	Interactions A×B	9.981	6	1.663	4.942	0.000
	Error	20.197	60	337		
	Total	400.853	72			

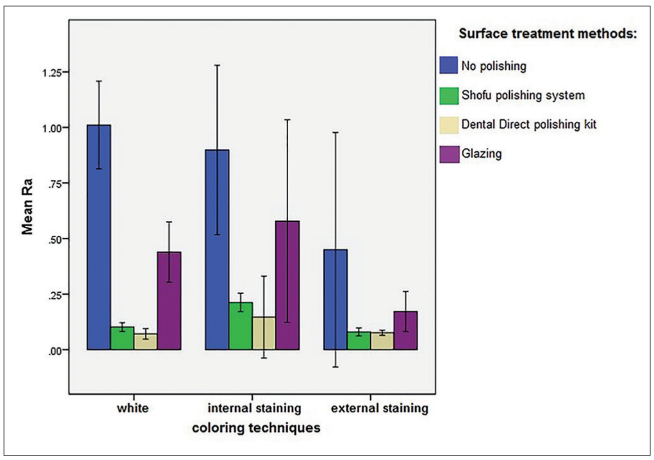

Figure 4: The mean and standard deviation of Ra (µm) of all subgroups affected by different surface treatment methods and coloring techniques.

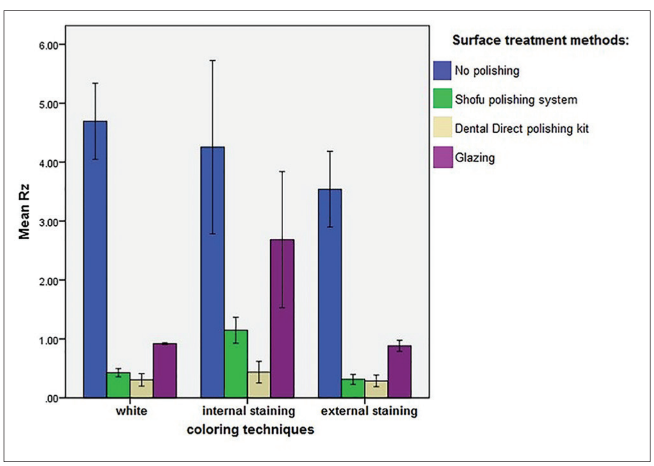

Figure 5: The mean and standard deviation of Rz (µm) of all subgroups affected by different surface treatment methods and coloring techniques.

significantly higher Rz values than the three other surface treatment methods ($P < 0.05$). The glazed subgroups had significantly higher Rz values than Shofu and dental direct polishing systems in internal and external staining groups. In the white coloring group, the Rz values of glazing subgroup were significantly higher than those polished with Dental Direct system ($P < 0.05$).

The results of two-way ANOVA also showed that the Ra parameter was significantly affected by the coloring technique ($P = 0.001$), surface treatment method ($P < 0.001$), and the interaction of these two parameters ($P = 0.049$). In white and internal staining groups, the mean surface roughness value (Ra) of the unpolished subgroup was significantly higher than the samples polished with Shofu and Dental Direct systems ($P < 0.05$). However, in the external staining group, no significant difference existed among different surface treatment methods ($P > 0.05$). Moreover, in the white zirconia group, surface roughness in the glazed specimens was significantly higher than that in the two other polishing systems ($P < 0.05$) and significantly lower than that in the unpolished subgroup.

Finally, the Rz and Ra values of Shofu and dental direct polishing systems were not significantly different among the three coloring techniques ($P > 0.05$).

The internal staining group had significantly higher Rz value than those in white and external staining groups when the specimens were glazed or polished with Shofu polishing kit ($P < 0.05$). However, the three coloring methods were not significantly different in unpolished specimens and those polished with dental direct polishing kit ($P > 0.05$).

SEM analysis confirmed the results of the roughness test [Figure 6]. Accordingly, the unpolished subgroups

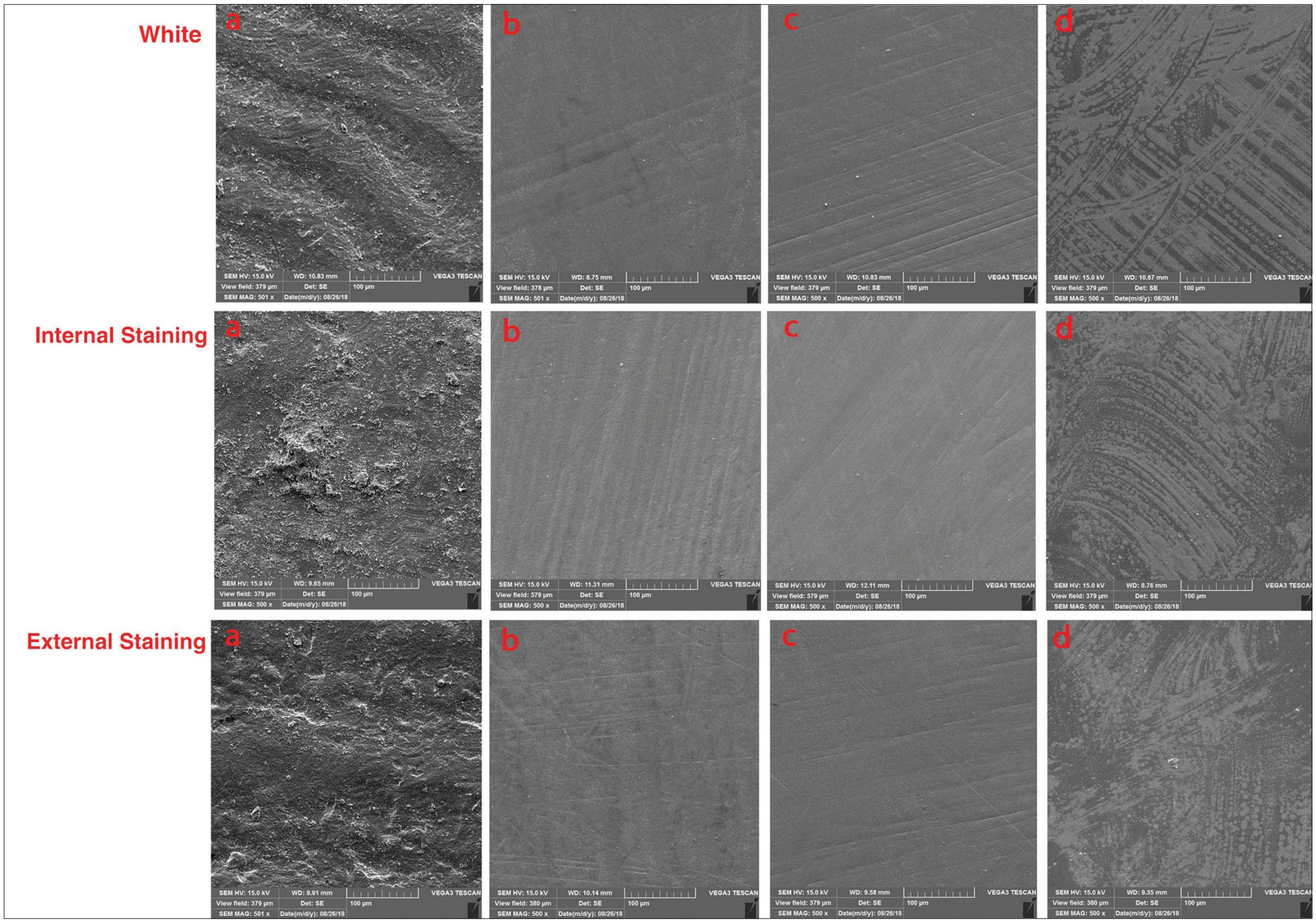

Figure 6: Scanning electron micrographs (×500) of 3 zirconia coloring groups: white, internal staining, external staining. (a) unpolished, (b) polished with Shofu polishing system, (c) polished with dental direct polishing system, (d) glazed.

colored with any coloring technique showed multiple deep multidirectional scratches with irregular texture. In glazing surface treatment, smoother and more uniform surface was created and the deep scratches appeared to be filled. After polishing with both Shofu and dental direct polishing systems, a fine granular surface was observed; most cracks could be removed by these polishing kits and presented a surface with a fine-grained and homogeneous texture.

DISCUSSION

The present study investigated the effect of different coloring techniques and surface treatment methods on the surface roughness of monolithic zirconia. The findings rejected the null hypothesis since both the coloring technique and surface treatment method significantly affected the surface roughness of monolithic zirconia.

The Ra and Rz values that are measured with a profilometer commonly describe the surface texture of zirconia specimens. These values represent the overall roughness of a surface and provide quantitative information about the surface texture.[18] While Ra was considered as the only roughness parameter in most previous studies,[18,23,24] the current study measured both Ra and Rz values to increase precision. Accordingly, when the Ra values are equal, the restoration with lower Rz value is considered to have less surface roughness, and consequently, would be more efficient.

Different studies suggested evaluation of both quantitative and qualitative parameters of surface roughness.[18,23,25] Therefore, the present study analyzed the surface roughness by using a profilometer and SEM to generate quantitative and qualitative roughness data, respectively. Inspired by Aravind *et al.*'s[14] and Park *et al.*'s study,[26] in the present study, a handpiece operating at a certain low speed was used, and surface treatment of all specimens was performed by a single operator to standardize the polishing parameters of the polishing systems as far as possible.

In this study, the results of surface roughness tests revealed that in all the three coloring techniques (white, internal, and external staining), the Rz values of the two polishing kits were not significantly different; however, it was significantly higher in the glazed samples. Furthermore, the Rz value in unpolished subgroup was significantly higher than the three other surface treatment methods. Meanwhile, the SEM analysis showed a fine-grained and homogeneous texture in specimens polished with both polishing kits, indicating that most cracks were removed by these two polishing systems. Whereas, the glazed subgroup had rougher surface compared with the two polished subgroups.

Several polishing kits are available and have already been investigated in a few studies.[27-29] Preis *et al*.[29] investigated the effectiveness of 14 two-step and three-step polishing kits on the surface roughness of ground monolithic zirconia. They found that, except for one system (Zircovis), all the polishing kits were equally effective in reducing the surface roughness of ground zirconia. The final surface roughness values of all polishing systems was below 0.2 µm (Ra), which was similar to or even less than the values observed in glazed specimens.[29]

According to Bollen *et al*.,[12] when surface roughness was below the threshold (Ra = 0.2 µm), bacterial retention was sort of farfetched. It was similar to the threshold of surface roughness (Ra = 0.2 µm) of dental prosthesis for prevention of plaque accumulation. The present findings showed that the surface roughness values in Shofu and dental direct polishing subgroups were below the clinically acceptable threshold. Whereas, the surface roughness in glazed and unpolished specimens was relatively above this threshold.

Mohammadi-Bassir *et al*.[25] reported that Meisinger and Busch kits intraoral zirconia polishing systems had similar effect on Ra and Rz values. Caglar *et al*.[28] compared the effect of three polishing systems (Meisinger zirconia polishing kit, EVE Diacera zirconia polishing kit, EVE Diapol porcelain polishing kit) on the surface roughness of monolithic zirconia. They observed smoother surfaces in all the three polishing groups compared with the unpolished specimens. They also reported that among the three polishing systems, zirconia polishing systems created smoother surfaces than the porcelain polishing system. However, neither significant difference was detected between the two zirconia polishing systems nor did Huh *et al*.[17] found any significant difference between surface roughness of two zirconia polishing systems (Meisinger and EVE Diacera zirconia polishing systems). Likewise, Park *et al*.[26] reported that EVE Diacera and CeraGloss HP zirconia polishing systems created similar surface roughness values. The findings of these four above-mentioned studies are in line with those of the present study, in terms of the similar polishing performance of the two zirconia polishing systems.

Park *et al*.'s[26] SEM evaluation showed that the CeraGloss HP zirconia polishing system left rougher surfaces compared with EVE Diacera zirconia polishing system. Such a difference in SEM analysis with the present study might be attributed to the number of employed polishing instrument in that study. In fact, they used two polishing instruments for standardization of the two polishing systems; while, CeraGloss HP polishing system is supposed to be used with three instruments. Another cause of difference can be the zirconia type as they used Prettau Zirconia and Zirmon; whereas, we used Zircostar. Undoubtedly, the surface properties of samples are likely to be influenced by the production procedures of zirconia block.

Generally, the material hardness affects the manufacturing of polishing systems. The ceramic particles used in porcelain polishing systems are of lower hardness compared with zirconia, which is likely to negatively affect the zirconia restorations.[17,26] It is recommended to employ zirconia polishing system for polishing the surface of monolithic zirconia restorations so that the flaws caused by the occlusal adjustment could be effectively handled.

On the other hand, Bai *et al*.[23] observed that the mean Ra was significantly higher in specimens polished with Komet polishing kit than those polished with Robinson brush and paste. They also noted that polishing the zirconia with Robinson brush and paste created the smallest wear areas on the antagonists. These contradictory results could be due to the use of different polishing kits in the two studies.

Amaya-Pajares *et al*.[27] found that Dialite zirconia polishing system created smoother surface for BruxZir zirconia and Zenostar polishing system created smoother surface for Zenostar zirconia. They also noted the surface roughness to be lower in polished specimens compared with the glazed zirconia specimens in both brands.

Janyavula *et al*.[11] ranked the surface roughness from the least rough to the roughest as polished zirconia, polished then reglazed zirconia, and glazed zirconia. They stated that the enamel wear was the lowest in polished zirconia, followed by polished and reglazed zirconia; the glazed zirconia showed the highest enamel wear. They announced the surface roughness of the substrates as a good predictor of the amount of resulting antagonist wear. They showed that the polished monolithic zirconia restorations could be indicated in high stress-bearing areas. This study also reported the highly polished zirconia to be more favorable than the glazed zirconia; so, if glazed restorations are to be used in esthetics areas, the surface would better to be first polished and then glazed. Similar to our study, different studies reported that compared with glazing, polishing the zirconia specimens yielded far smoother surface and less antagonist enamel wear.[23,30,31]

All the four above-mentioned studies unanimously concluded that using zirconia in crowns and FDPs with no veneering material requires the surface to be highly polished if the occlusal adjustments are performed with coarse diamonds. In these studies, polishing was preferred to glazing since it created a smoother surface and decreased the plaque adhesion. Whereas, the glazed surfaces wear off more rapidly by the chairside occlusal adjustment or shortly after being in function and expose the underlying rough surface of unpolished ceramic. Therefore, some researchers recommend polishing the ceramics before glazing to prevent the opposing enamel wear.[30,32]

Mohammadi-Bassir *et al*.[25] showed that despite the equal surface roughness of the polished and glazed specimens, the flexural strength was far more in polished group. Guazzato *et al*.[33] believed that heat treatment decreased the monoclinic phase because of the reverse phase transformation. Y-TZP is not stable over time; furthermore, warm and humid environment of the oral cavity may cause low-temperature degradation. On the other side, glazing subjects the zirconia to firing and moisture, which may affect the flexural strength and put it at risk of low-temperature degradation.[34] Low-temperature degradation of Y-TZP reduces the strength and increases the surface roughness, which subsequently increases the risk of wear of the opposing dentition and translucency.[35] Sabrah *et al*.[36] reported that despite having the smoothest surface in the glazed group, wear behavior of the glazed monolithic zirconia was not preferable to unglazed group. Heintze *et al*.[37] detected superior antagonist wear in specimens with glazed surfaces compared with polished ones. These two studies agreed on the fact that despite the excellent surface smoothness achieved by glazing, the durability of glazed restoration is not well-established in function. Consequently, appropriate polishing can help preventing or decreasing the antagonist abrasion.

In contrast to the present study, there was another study, which reported achieving smoother surfaces in glazed rather than polished ceramics. Furthermore, they noticed that the enamel wear was significantly lower in glazed than polished Y-TZP ceramic surfaces.[38] Such contradictions could be due to the different polishing kits and different types of zirconia employed in those studies.

A review study,[39] which compared the glazing and mechanical polishing, revealed that the heterogenic results of the included studies strongly depended on the chosen glazing and polishing methods. The present study also showed that the internal staining group had significantly higher Rz value than the other staining methods when the specimens were glazed and polished with Shofu polishing kit. Hence, it was noted that internal staining with coloring substance impaired and roughened the surface of the zirconia in these two surface treatment methods. Bai *et al*.[23] noted significant difference between the stained and white zirconia regarding the wear depth; but, these two coloring methods were not significantly different in terms of antagonist wear area and surface roughness. It indicated that treatment with coloring substances impaired the wear resistance of zirconia surfaces and did not affect the antagonists. Park *et al*.[31] showed that the polished zirconia group had significantly less antagonistic tooth wear than the stained and glazed group since the staining and glazing treatment includes the porcelain materials, and the zirconia substructure should be polished before any surface treatment because when the staining gets worn, the underlying rough surface may accelerate wear.

One of the limitations of the present study was its *in vitro* nature; while, the efficiency of a polishing technique might be different under clinical conditions. Moreover, since different outcomes can be expected with different types of zirconia and polishing protocols, further investigations are recommended to evaluate the surface roughness of other types of zirconia and other polishing protocols.

CONCLUSION

Within the limitations of this *in vitro* study, it can be concluded that for all the three coloring techniques (white, internal, and external staining), the surface roughness of the two polishing systems does not have any significant difference. Moreover, the surface roughness of glazed specimens is significantly higher than the two groups of polished specimens and lower than the unpolished ones.

The surface roughness of the internal staining zirconia group is significantly higher than the other staining methods for the specimens, which were glazed and those polished with Shofu polishing system. However, among the subgroups of unpolished and polished with dental direct polishing kit, there was no significant difference between the Rz values of the specimens stained with different coloring methods.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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