The effect of various polishing systems on surface roughness and phase transformation of monolithic zirconia

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PURPOSE. The purpose of this study was to evaluate and compare three polishing systems on the surface roughness and phase transformation of monolithic zirconia. **MATERIALS AND METHODS.** 100 disk shaped specimens (10 mm diameter, 3 mm thickness) were fabricated from monolithic zirconia blocks. 20 specimens were left as a control group and remaining specimens were grinded by diamond bur to simulate the occlusal adjustments. Grinded specimens were randomly divided into 4 groups: group G (no polishing), group M (Meisinger, zirconia polishing kit), group E (EVE Diacera, zirconia polishing kit), and group P (EVE Diapol, porcelain polishing kit). Surface roughness was measured with profilometer and surface topography was observed with SEM. XRD analysis was performed to investigate the phase transformation. Statistical analysis was performed with one-way ANOVA and Tukey's post hoc tests at a significance level of P=.05. **RESULTS.** All polishing groups showed a smoother surface than group G. Among 3 polishing systems, group M and group E exhibited a smoother surface than the group P. However, no significant differences were observed between group M and group E (P>.05). Grinding and polishing did not cause phase transformations in zirconia specimens. **CONCLUSION.** Zirconia polishing systems created a smoother surface on zirconia than the porcelain polishing system. Phase transformation did not occur during the polishing procedure. ***[J Adv Prosthodont 2018;10:132-7]***

KEYWORDS: Grinding; Monolithic zirconia; Phase transformation; Polishing; Surface roughness

INTRODUCTION

Over the last decades, there have been a large number of dental materials and new ceramic systems have been successfully introduced for clinical use in dentistry.[1] Recently, the popularity of Y-TZP ceramics (yttrium-stabilized tetragonal zirconia polycrystalline) has increased for prosthetic dentistry due to its excellent mechanical properties, biocompatibility and esthetic potential compared to conventional dental ceramics.[1-4] Currently, there are two types of zirconia restorations used; these are zirconia veneered with feldspathic porcelain (ZVP) and monolithic zirconia (MZ). Chipping or fracture of the veneering layer is the most commonly reported clinical complication for ZVP.[5,6] MZ restorations which contain only zirconia are directly exposed to the oral environment that does not require veneered with esthetic material. Thus, the absence of veneering porcelain could eliminate the chipping problem.[7-10] Although the precision of computer-aided design and computer-aided manufacturing (CAD/CAM) technology has been a significant progress, the intraoral adjustments of the restorations are still needed for adaption, occlusion and to ensure the emergence profile.[6,11] Because of high surface hardness of zirconia, diamond burs are used to carry out clinical adjustment which may cause loss of glaze layer and surface smoothness.[12] The rough and irregular surface of restorations can lead to increased catastrophic wear of opposing enamel and dental restorations.

Intraoral polishing systems have become an alternative method for re-glazing, which is important to prevent or minimize rapid wear of the opposing teeth. In addition, polishing improves the longevity and esthetics of restorations

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by eliminating the defects created by surface grinding.[13,14]

Zirconia is a polymorphic metastable material and exists in several major phases: monoclinic (m), cubic (c) and tetragonal (t). However, this material undergoes microstructural changes by the stress application and phase transformation from t phase into the m phase.[15-18] As a result, the increase in m phase caused the degradation of mechanical properties of Y-TZP which compromises the predictability of longevity of the prosthetic rehabilitation.[19] Clinical adjustments procedure may affect the phase transformation and weaken the zirconia.[18,20,21] Some studies remarked that although grinding procedure degrades the strength of zirconia, no significant effect on phase transformation was observed.[21,22] According to our knowledge, however, whether typical clinical procedures that generate heat, such as polishing, affect the phase transformation of monolithic zirconia is unclear.

Although there are a great number of studies about polishing systems for porcelain restorations,[13,19,23,24] limited information is accessible on the productivity of zirconia polishing.[6,25] Therefore, the aim of this study was to evaluate and compare the effect of different polishing systems on surface roughness and phase transformation of monolithic zirconia. The null hypothesis of this study was that surface roughness and phase transformation is influenced by clinical adjustment procedures for monolithic zirconia.

MATERIALS AND METHODS

100 disk shaped specimens (10 mm diameter 3 mm thickness) were fabricated from presintered monolithic zirconia blocks (Katana Zirconia HT, Kuraray-Noritake, Aichi, Japan) by CAD/CAM milling (Yenadent DC40, Yenadent Ltd., Istanbul, Turkey) and sintered in a high temperature furnace (Everest Therm; KaVo Dental GmbH, Biberach, Germany) at 1500°C for 7 hours according to the manufacturer's introductions to obtain final dimensions. Initial polishing was carried out for all specimens using a silicon carbide rotary abrasive (NTI Ceramic Polisher; Kahla GmbH, Thuringia, Germany). Final polishing was performed using 500 grit and 1500 grit abrasive papers for standardization of the surface roughness.

20 specimens were left as a control group (group C), the surfaces of the remaining 80 specimens were grinded with a diamond rotary instrument (product code: 6830RL, Komet-Brasseler, GmbH, Lemgo, Germany) and a high-speed hand piece (Ti-Max X600L; NSK, Tochigiken, Japan) to simulate the occlusal adjustment process by the same examiner for all specimens. Specimen's surfaces were grinded twice in 10 second intervals for a total of 20 seconds under water-coolant. Twenty grinded specimens were left as group G and then specimens were randomly divided into three groups according to the polishing systems. Two zirconia polishing systems group M (Meisinger, Luster for zirconia intra-oral adjustment kit, Hager & Meisinger GmbH, Dusseldorf, Germany), group E (EVE Diacera, EVA Ernst Vetter GmbH, Pforzheim, Germany) and one porcelain polishing system group P (EVE Diapol, EVA Ernst Vetter GmbH, Pforzheim, Germany) were examined for polishing performance (Table 1). All polishing systems consist of 3 polishing instruments and they were used for application according to manufacturer instructions. Polishing was performed for each instrument in one direction for 30 seconds by using low-speed handpiece (Ti-Max X600L; NSK, Tochigiken, Japan) and then carried out again at an angle of 90 degrees for 30 seconds in the same specimen by the same examiner.[6] The RPM during polishing was set to 80% of the maximum value recommended by manufacturer.

After polishing procedures, the specimens were rinsed with air-water spray for 15 seconds and then ultrasonically cleaned (Euronda, Eurosonic Energy, Vicenza, Italy) for 1 minute in 100% distilled water and then air dried.

Table 1. Polishing systems used in the study

Group	Brand/Manufacturer	Composition	Recommended revolution (RPM)	Lot number
M	Luster for zirconia intra-oral adjustment kit, Meisinger, Hager&Meisinger GmbH	Stage 1: Pregrinding	8000 - 12000	A77751
		Stage 2: Smoothing & pre-polishing	7000 - 12000	
		Stage 3: High-gloss polishing	7000 - 12000	
E	EVE Diacera, EVA Ernst Vetter GmbH	Stage 1: Pregrinding	7000 - 12000	240231
		Stage 2: Smoothing & pre-polishing	7000 - 12000	
		Stage 3: High-gloss polishing	7000 - 12000	
P	EVE Diapol, EVA Ernst Vetter GmbH	Stage 1: Removing	7000 - 12000	230893
		Stage 2: Smoothing	7000 - 12000	
		Stage 3: High-luster polishing	7000 - 12000	

The level of zirconia phase transformation was determined by measuring the peak intensity ratio of the x-ray diffraction (XRD) pattern. A crystal structure of the specimens was made by X-ray diffractometer (XRD, Smartlab-201307, Rigaku Corporation, Tokyo, Japan) using monochromatic CuK α radiation. Scanning was performed on the marked surface at a 0.01 degree step range between the intervals of 20 and 40 2Θ degrees, where Θ is the angle of reflection.

Surface roughness (Ra, μm) of the specimens was measured using a profilometer (Perthometer M2, Mahr GmbH, Göttingen, Germany). Three measurements were performed per specimen in the treated surface. The roughness of each specimen was calculated by the arithmetic mean of three measurements (μm). One specimen for each group was separated for SEM evaluations (Zeiss EVO LS 10, Carl Zeiss, Oberkochen, Germany) under ×1000 magnification to evaluate the effect of polishing procedure on the surface topography.

The power analysis was calculated according to the previous article[25] by considering the effect size = 2, beta error = 0.80 and alpha error = 0.95. Finally it was decided to use 20 specimens for each group could be adequate for statistical evaluation. The normality of the data was detected with Shapiro-Wilk test. One-way ANOVA and Tukey's post hoc tests were used for comparing the differences at a significance level of $P < .05$.

RESULTS

The mean and standard deviation (SD) values of surface roughness (Ra) were shown in Table 2. The statistical analysis confirmed that polishing system has a statistically significant effects on surface roughness ($P < .05$). The highest surface roughness values were exhibited for Group G (1.77 μm). All polishing systems exhibited a significantly smoother surface than grinding group ($P < .05$). Among 3 polishing systems, group M and group E exhibited a smoother surface than the group P. However, no significant differences were observed between group M and group E ($P > .05$).

Table 2. Mean and standard deviations of surface roughness values (um)

Group	N	Mean (SD)
Control	20	1.11 (0.27)[a]
G	20	1.77 (0.26)[b]
M	20	0.28 (0.11)[c]
E	20	0.28 (0.07)[c]
P	20	0.78 (0.14)[d]

Same letters indicates the values that were not statistically different ($P > .05$).
SD: Standard deviation, Control: Sintered zirconia, Group G: Grinding, Group M: Meisinger polishing systems, Group E: EVE Diacera polishing systems, Group P: EVE Diapol polishing systems

SEM analysis proved that grinding and polishing procedure modified the topographic pattern (Fig. 1, Fig. 2, Fig. 3, Fig. 4, Fig. 5). For control group, periodic textures with uniform directionality resulting from the CAD/CAM process were identified (Fig. 1). Grinding with diamond bur created parallel, deep scratches following the direction of bur movement on the surface of zirconia specimen (Fig. 2). The surfaces were progressively smoothened, which confirms the surface roughness values after using the polishing systems (Fig. 3, Fig. 4, Fig. 5). All polishing surface presented similar SEM images, however, some deep grinding grooves could not be entirely removed, and some striations were observed for group P (Fig. 5).

XRD data was shown in Fig. 6. All groups exhibited similar XRD patterns. The data indicated that neither the pretreatment simulating an occlusal adjustment nor the series of polishing processes caused the occurrence of phase transformations within the zirconia specimens.

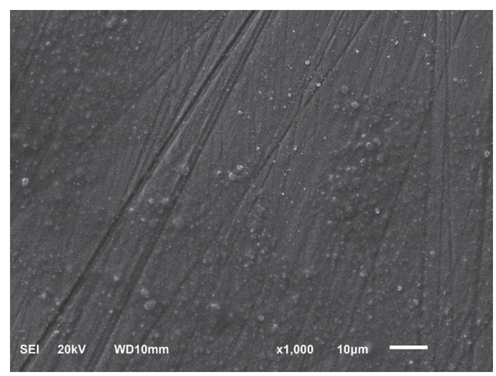

Fig. 1. Scanning electron microscopy image (×1000 magnification) of the zirconia specimens as received, control group.

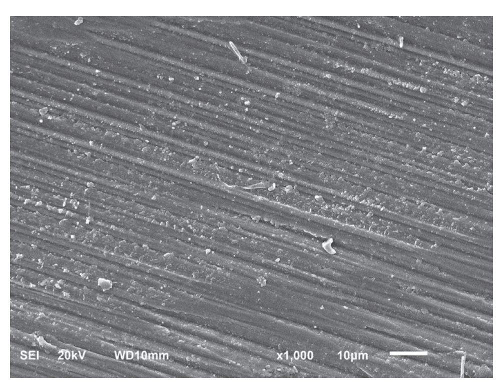

Fig. 2. Scanning electron microscopy image (×1000 magnification) of the grinded zirconia specimens, Group G.

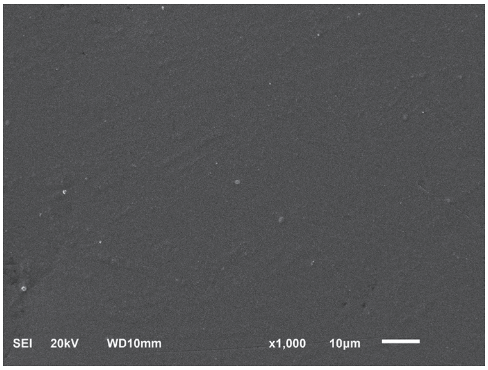

Fig. 3. Scanning electron microscopy image (×1000 magnification) of the zirconia specimens after polishing with Meisinger system, Group M.

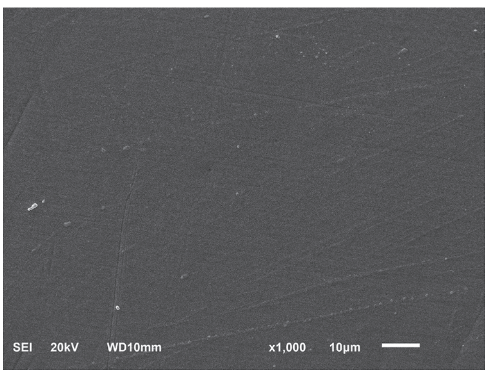

Fig. 4. Scanning electron microscopy image (×1000 magnification) of the zirconia specimens after polishing with EVE Diacera system, Group E.

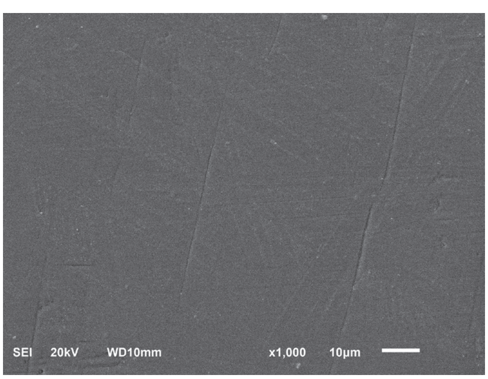

Fig. 5. Scanning electron microscopy image (×1000 magnification) of the zirconia specimens after polishing with EVE Diapol system, Group P.

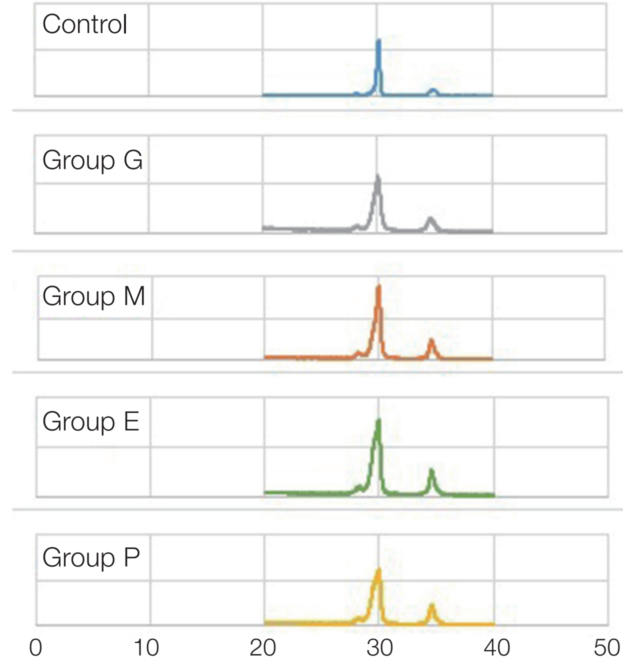

Fig. 6. XRD patterns of zirconia specimens.

DISCUSSION

This study investigated the effect of polishing systems on surface roughness and phase transformation on monolithic zirconia. The null hypothesis that surface roughness and phase transformation is influenced by clinical adjustment procedures for monolithic zirconia was partially rejected because no influence on phase transformation was detected by polishing and grinding. However, surface roughness of monolithic zirconia was influenced by polishing systems. The results showed that surface roughness values were significantly influenced by occlusal adjustments. Grinding increased the surface roughness values, however, polishing decreased. Zirconia polishing systems exhibited a significantly smoother surface than porcelain polishing systems ($P < .05$). There was no phase transformation within the zirconia after polishing or grinding.

Chairside adjustments such as grinding and polishing are frequently applied during the prosthetic rehabilitation. Grinding process which creates a very rough surface is done for establishing an optimal occlusal contacts. This rough surface has to be smoothened by glazing or polishing after clinical adjustments. Sabrah *et al.*[26] evaluated the surface roughness and wear behavior of glazed, grinded and polished monolithic zirconia. They stated that although glazed group showed the smoothest surface, wear behavior of glazed monolithic zirconia was not preferable to unglazed group. Heintze *et al.*[27] reported that glazed surfaces raised superior antagonist wear than polished surfaces. The common result of these studies is that the glaze application showed the best surface smoothness but the longevity of glaze is not well-established when restorations are in function. Therefore, prevention or reduction of antagonist abrasion can be achieved by appropriate polishing. By this way, in the current study, we evaluated the polishing effect after grinding procedure instead of glazing.

Although there are various studies about polishing methods and systems, there are not any certain decisions about handpiece speed, abrasive characteristics, polishing load or application time.[1,6,13,19,20,24,25] These parameters make it difficult to compare studies on the effects of polishing procedures on zirconia. In the present study, similar to the studies by Camacho *et al.*,[28] Aravind *et al.*[29] and Park *et al.*,[6] a handpiece operating at a certain moderate speed under water cooling was used, and surface treatment of all specimens was performed by the same operator to standardize the polishing parameters of the polishing systems as much as possible. Grinding with the diamond burs caused significant changes in surface roughness values; as expected, the highest surface roughness values were found for grounded group (1.77 µm). The surface roughness values decreased after polishing procedure and the smoothest surfaces were found for group M (0.28 µm) and Group E (0.23 µm). Bollen *et al.*[30] suggested that the bacterial retention could not be expected below the threshold surface roughness value (Ra = 0.2 µm). These findings are similar to threshold surface roughness values (Ra = 0.2 µm) of dental prosthesis for prevention of plaque accumulation which means that the surface roughness values for group M and group E were clinically acceptable. However, group P (0.78 µm) exhibited a rougher surface than this threshold. Similar to the present study, Park *et al.*[6] stated that porcelain polishing systems exhibited higher surface roughness values than zirconia polishing systems on monolithic zirconia. The polishing systems are manufactured according to the material's hardness. Porcelain polishing systems contain ceramic particles which have a lower hardness than zirconia, so their effectiveness is questionable when used with zirconia restorations.[6,25] Therefore, the surface of monolithic zirconia restorations should be polished with a zirconia polishing system to control the flaws introduced by the occlusal adjustment.

Huh *et al.*[25] used Meisinger and EVE Diacera zirconia polishing systems to polish grinded surface and they found surface roughness values similar to the present study. However, Park *et al.*[6] stated a rougher surface for EVE Diacera polishing system. The differences may be attributed to the number of polishing instrument which they used. Park *et al.*[6] used 2 polishing instruments in EVE Diacera polishing system to standardize other polishing systems they used in their study. However; in the present study, 3 polishing instruments were used. Also Park *et al.*[6] used Prettau Zirconia and Zirmon in their study. However, in the present study, we used Katana Zirconia HT. Production procedures of different zirconia block may affect the surface characteristics of tested specimens.

Although there were no significantly differences on surface roughness between two zirconia polishing systems, SEM evaluations showed that group M exhibited a smoother surface than group E. The differences in the durability of two polishing systems may be due to the component of each system. Additional studies are needed to investigate the relationship between the component of the polishing system and polishing performance.

Zirconia is completely crystalline thus phase changes in the material could be assessed by XRD analysis. Surface manipulation conducted during occlusal adjustments may result in local heating leading to t to m phase transformation.[18,20-22] Karakoca and Yilmaz[21] studied about phase transformation of zirconia after grinding and sandblasting and stated grinding has no significant effect on phase transformation. However, Lee *et al.*[31] reported that grinding procedure caused a small amount of monoclinic phase in zirconia by different diamond burs. The reason of reverse transformation in the study may be related to an increase in local temperature during grinding. In the present study, grinding was applied under water cooling to prevent the monolithic zirconia from reverse phase transformation. XRD analysis indicated that grinding before polishing procedure did not cause phase transformation on monolithic zirconia. Huh *et al.*[25] and Al-Haj Husain *et al.*[32] reported that neither grinding nor polishing led to a phase transformation of monolithic zirconia, which is similar to the present study. Despite these studies, Park *et al.*[6] indicated that the monolithic phase volume was increased to 0.09% when polishing procedure was applied for 8 minutes. The differences among these studies were about the application time and procedure. According to these results, in the present study, polishing application time was restricted for 3 minutes totally to prevent the phase transformation.[6]

This study has some limitations. Only a single type of monolithic zirconia block was used, and coloring and staining were not done. Also, the effect of polishing and grinding on flexural strength was not evaluated in the present study. All specimens were produced and evaluated under *in-vitro* conditions, so this study cannot reflect the conditions of clinical applications exactly. Further structured *in vivo* studies with more comparisons should be made.

CONCLUSION

Clinically acceptable polishing performance was obtained by all examined zirconia polishing systems. Zirconia polishing systems exhibited significantly lower surface roughness values than the porcelain polishing test group ($P < .05$).

Neither polishing nor grinding caused detrimental phase transformation on monolithic zirconia.

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