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# Effect of grinding and polishing on roughness and strength of zirconia

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## ABSTRACT

**Statement of problem.** The clinical applications of high-translucency monolithic zirconia restorations have increased. Chairside and laboratory adjustments of these restorations are inevitable, which may lead to increased roughness and reduced strength. The influence of grinding and polishing on high-translucency zirconia has not been investigated.

**Purpose.** The purpose of this in vitro study was to compare the roughness averages (Ra) of ground and polished zirconia and investigate whether roughness influenced strength after aging.

**Material and methods.** High-translucency zirconia disks were milled, sintered, and glazed according to the manufacturer's recommendations. Specimens were randomized to 4 equal groups. Group G received only grinding; groups GPB and GPK received grinding and polishing with different polishing systems; and group C was the (unground) control group. All specimens were subjected to hydrothermal aging in an autoclave at 134°C at 200 kPa for 3 hours. Roughness average was measured using a 3-dimensional (3D) optical interferometer at baseline (Ra1), after grinding and polishing (Ra2), and after aging (Ra3). A biaxial flexural strength test was performed at a rate of 0.5 mm/min. Statistical analyses were performed using commercial software ($\alpha$=.05).

**Results.** Group G showed a significantly higher mean value of Ra3 (1.96 ±0.32 μm) than polished and glazed groups ($P$<.001), which showed no statistically significant difference among them (GPB, 1.12 ±0.31 μm; GPK, 0.88 ±0.31 μm; C: 0.87 ±0.25 μm) ($P$>.05). Compared with baseline, the roughness of groups G and GPB increased significantly after surface treatments and after aging, whereas aging did not significantly influence the roughness of groups GPK or C. Group G showed the lowest mean value of biaxial flexural strength (879.01 ±157.99 MPa), and the highest value was achieved by group C (962.40 ±113.84 MPa); no statistically significant differences were found among groups ($P$>.05). Additionally, no significant correlation was detected between the Ra and flexural strength of zirconia.

**Conclusions.** Grinding increased the roughness of zirconia restorations, whereas proper polishing resulted in smoothness comparable with glazed surfaces. The results provide no evidence that grinding and polishing affect the flexural strength of zirconia after aging. (J Prosthet Dent 2018;119:626-31)

Monolithic zirconia restorations are a promising option in high-stress-bearing areas. They eliminate the complication of veneering porcelain chipping and exhibit excellent biological and mechanical properties.[1] Zirconia is a white opaque material that exhibits low translucency and a high refractive index (2.1 to 2.2).[2] Translucency is determined by the material's ability to transmit light and is influenced by the size and distribution of zirconia grains, fabrication processing, and additives used to enhance the color and properties.[2,3]

Different strategies have been used to improve the translucency of yttrium-stabilized zirconia polycrystal (Y-TZP), including increasing the yttria content; introducing cubic phase zirconia; reducing the amount of $Al_2O_3$ from 0.25 to 0.1% of weight, which is added during manufacturing for aging resistance; adding 0.2 mol% of $La_2O_3$ to Y-TZP; modifying the sintering time and temperature; and reducing the grain size, which can effectively eliminate light scattering and improve zirconia translucency.[3-5] Another process mills the zirconium oxide powders into smaller particles, which are then mixed with a

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## Clinical Implications

By investigating different grinding and polishing systems, this study provided information on best practices when adjustments are needed on anatomically contoured zirconia crowns and on whether these adjustments will influence the durability of the restoration.

suitable binder to increase the compaction and density, eliminating the porosity that highly affects light scattering and translucency.[5,6]

Ideally, grinding and adjustment of anatomically contoured zirconia restorations should be avoided because they can produce rough surfaces. However, for many restorations, it is necessary to optimize occlusion, proximal contacts, and axial contour. Roughness is associated with plaque accumulation, dental caries, gingival inflammation, periodontal disease, and wear of the opposing tooth structure.[7,8] A recent study found a statistically significant negative correlation between the surface roughness and strength of zirconia, using the 3-point bend test.[9] Polishing can reduce surface flaws, contributing to the greater flexural strength of restorations.[10,11] Various finishing and polishing systems are available for zirconia restorations that include diamond rotary instruments of various sizes and shapes and diamond-impregnated silicone cups, wheels, and points made of natural or synthetic diamond grit grades.[12,13] Huh et al[14] found that some zirconia polishing systems produced significantly smoother surfaces than others, but all were clinically acceptable.

Grinding has 2 counteracting effects on zirconia: either it produces surface compressive stress that can positively enhance crack healing and increase the material strength by transformation toughening or it can induce surface flaws that may exceed the depth of the compressive layer and negatively influence the strength of the material.[15] Microcracks can be triggered by a number of stimuli such as thermal changes, humidity, airborne-particle abrasion, and grinding.[16,17]

Aging of anatomically contoured Y-TZP restorations could be more crucial because restorations are in direct contact with oral fluid.[5] Hydrothermal aging of zirconia, known as low-temperature degradation, can occur over time within the temperature range of 65°C to 500°C in the presence of water and other solvents.[17] Although this mechanism is very slow in oral temperatures, zirconia restorations are exposed to other factors such as constant humidity, thermal changes, pH fluctuation, and repeated high occlusal loads due to mastication and parafunctional habits that can accelerate the aging process and reduce the material's fracture resistance.[17,18] Also, the chemical composition, the microstructure of various brands of high-translucency zirconia, the thickness of the restoration, and the processing can influence resistance to aging.[19,20] Although polishing zirconia did not trigger any phase transformation,[14] in vitro aging of zirconia for 1 hour in an autoclave at 134°C at 200 kPa resulted in a significant tetragonal-to-monoclinic transformation that has, theoretically, the same effect as 3 to 4 years in vivo at 37°C.[17] Even though Y-TZP exhibits an excellent flexural strength of 900 to 1400 MPa,[21,22] some studies found that the mean flexural strength of aged zirconia decreased and the monoclinic phase increased with aging.[17,23-25] However, the effect of aging on reducing flexural strength was not the same for different high-translucency zirconia brands.[20]

The effect of grinding and polishing high-translucency zirconia restorations is variable, and the effect on long-term prognosis of these restorations is unknown. The primary objective of this study was to measure the Ra and biaxial flexural strength of aged high-translucency zirconia specimens that received grinding and polishing, by using different protocols and to determine the roughness changes after different surface treatments and after aging in comparison with baseline roughness. The second objective was to investigate whether roughness influences the mechanical properties of aged zirconia. The null hypotheses were that no differences would be found in mean roughness average or mean flexural strength among the ground, polished, and glazed groups and that no correlation would be found between roughness and flexural strength.

## MATERIAL AND METHODS

A total of 44 disks (15×1.5 mm) were fabricated by milling Y-TZP blanks (Tizian Blank Translucent 98-mm Zirconium; Schütz), using a milling machine (Tizian Cut 5 smart machine; Schütz). Specimens were then sintered in a furnace (Mihm-Vogt Dental Gerätebau GmbH &Co. KG) at 1500°C for 2 hours of holding time and a heating rate of 5°C/minute. The specimens were ultrasonically cleaned (Quantrex LR 606) with ethyl alcohol for 10 minutes and air dried. Each specimen's diameter and thickness was checked with a digital caliper (Model 01407A; Neiko) for standardization. Each specimen was glazed (Zenostar Magic Glaze; Ivoclar Vivadent AG) and fired in a furnace (Programat P300; Ivoclar Vivadent AG) at 880°C, according to the manufacturer's instructions.

Specimens were randomly allocated to 4 groups (n=11) by using statistical software (R v3.1.2; The R Foundation). Each specimen was labeled using a heat-resistant permanent pen (Super permanent ink, extra fine point; Sharpie Industrial). A bench vise (model

BV-VB; Bessey) with a vacuum base was used to hold a custom-made acrylic resin plate on which specimens were securely placed. The straight electric handpiece (A-Dec EA-51LT; A-Dec Inc) was aligned perpendicular to the fixed jaw of the vise to facilitate movement with standardized pressure and the direction of grinding and polishing. Grinding was done in a sweeping motion forward and backward for 30 seconds, and polishing with stroke movements for 30 seconds for each tool was done by a single trained operator (W.K.), following the sequence and speed recommendations for each system. Each group received the specified surface treatment. Group G was ground but not polished. Group GPB received grinding and polishing with the 2-step Brasseler zirconia polishing kit (Dialite ZR polishing wheels; Brasseler USA). Group GPK received grinding and polishing with the 2-step Komet polishing kit (Komet ZR Flash Polisher; Gebr. Brasseler). Group C was the control group and was not ground or polished.

After receiving their respective surface treatments, the specimens were ultrasonically cleaned for 10 minutes with water and then air dried. The specimens were subjected to aging to simulate the effect of a humid oral environment. They were placed in autoclave-safe trays and bags and exposed to 6 cycles of 30 minutes each with no drying time between the cycles. The total exposure time was 3 hours at a temperature of 134°C and a pressure of 200 kPa.

The Ra was measured using a 3D optical interferometer (Zygo New View 600; Zygo Corp) at 3 different stages of the study. For each specimen, Ra1 was measured after glazing, Ra2 after grinding and polishing, and Ra3 after aging. Each specimen was centered on a fixed stage. Focus and light were adjusted, and images with a 526×702 μm field of view were acquired using an ×10 objective and ×1 zoom. Bipolar scan modes for 10 seconds and 40 μm of vertical scan length were selected on the measurement control panel. Images were captured with a high-resolution camera and displayed and analyzed using software (MetroPro v8.3.5; Zygo Corp). The analysis control panel was adjusted to subtract plan to remove spikes of 2.50 μm and to fill missing data points using adjacent valid data points with an iterative algorithm. The mean value of Ra was calculated in nanometers, and the 3D image of the surface profile was shown.

Specimens were subjected to a biaxial flexure strength test according to International Organization for Standardization standard 6872.[18] Maximum compressive load was measured in N, using a universal testing machine (model 5566; Instron Corp). Each specimen was positioned on a circular fixture with 3 support projections, which were equidistant from each other. A flat circular tungsten piston (Ø=2 mm) was used to apply an increasing load (0.5 mm/min) until catastrophic failure occurred. Settings were controlled, and results were displayed using software (Bluehill v2; Instron Corp). Flexural strength was calculated using the appropriate equation.[26]

**Table 1.** Means ±SD average roughness values at baseline, after grinding and polishing, and after aging (μm)*

| Group | Ra | Mean | ±SD | *P* |
|---|---|---|---|---|
| G (grinding) | Ra1 (after glazing) | 0.80[a] | 0.16 | <.001 |
| | Ra2 (after grinding) | 1.70[b] | 0.44 | |
| | Ra3 (after aging) | 1.96[c] | 0.32 | |
| GPB (polishing with Brasseler) | Ra1 (after glazing) | 0.67[d] | 0.06 | .002 |
| | Ra2 (after polishing) | 1.00[e] | 0.31 | |
| | Ra3 (after aging) | 1.12[f] | 0.31 | |
| GPK (polishing with Komet) | Ra1 (after glazing) | 0.70 | 0.12 | .140 |
| | Ra2 (after polishing) | 0.81 | 0.26 | |
| | Ra3 (after aging) | 0.88 | 0.31 | |
| C (glazed Control)* | Ra1 (after glazing) | 0.79 | 0.20 | .180 |
| | Ra3 (after aging) | 0.87 | 0.25 | |

Ra1, roughness average at baseline; Ra2, after grinding and polishing; Ra3, after aging. Repeated measures ANOVAs were conducted to compare between means of Ra1, Ra2, and Ra3 within groups G, GPB, and GPK ($\alpha$=.05). Pairwise tests were used for groups G and GPB to check for significant differences among Ra1, Ra2, and Ra3. Different superscript letters correspond to statistically significant difference between Ra means within each group (*P*<.017). *Paired *t* test variables compared between means of Ra1 and Ra3 (*P*<.05).

A sample size calculation was derived using software (nQuery Advisor v7.0; Informer Technologies, Inc). Based on previous published results,[7] an effect size of $\Delta^2$=.28 was assumed. A Type I error rate of $\alpha$=.05 was specified. Under the above assumptions, a sample size of n=11 per group was adequate to obtain a power of 80%. Comparisons among the groups for Ra2, Ra3, and flexural strength were made using 1-way analysis of variance (ANOVA), whereas for Ra1, the Kruskal-Wallis test was used to make comparisons among the groups. A post hoc analysis was performed using the Tukey honest significant differences test for statistically significant ANOVA results. Repeated measures ANOVA was performed for group G, GPB, and GPK, to compare among the means of Ra1, Ra2, and Ra3 within each group. A paired *t* test with Bonferroni correction was conducted for post hoc tests for statistically significant repeated measures ANOVA results. The paired *t* test was used to compare between the means of Ra1 and Ra3 for group C. The Pearson correlation was used to determine the association between roughness and flexural strength. All analyses were performed using software (IBM SPSS Statistics v22; IBM Corp) ($\alpha$=.05).

## RESULTS

The highest Ra3 mean ±SD was recorded for group G, followed by group GPB. Groups GPK and the C showed the lowest Ra3 means and were approximately equal to each other (Table 1). ANOVA showed a statistically significant difference of Ra3 between groups (*P*<.001). Group G showed significantly higher surface roughness

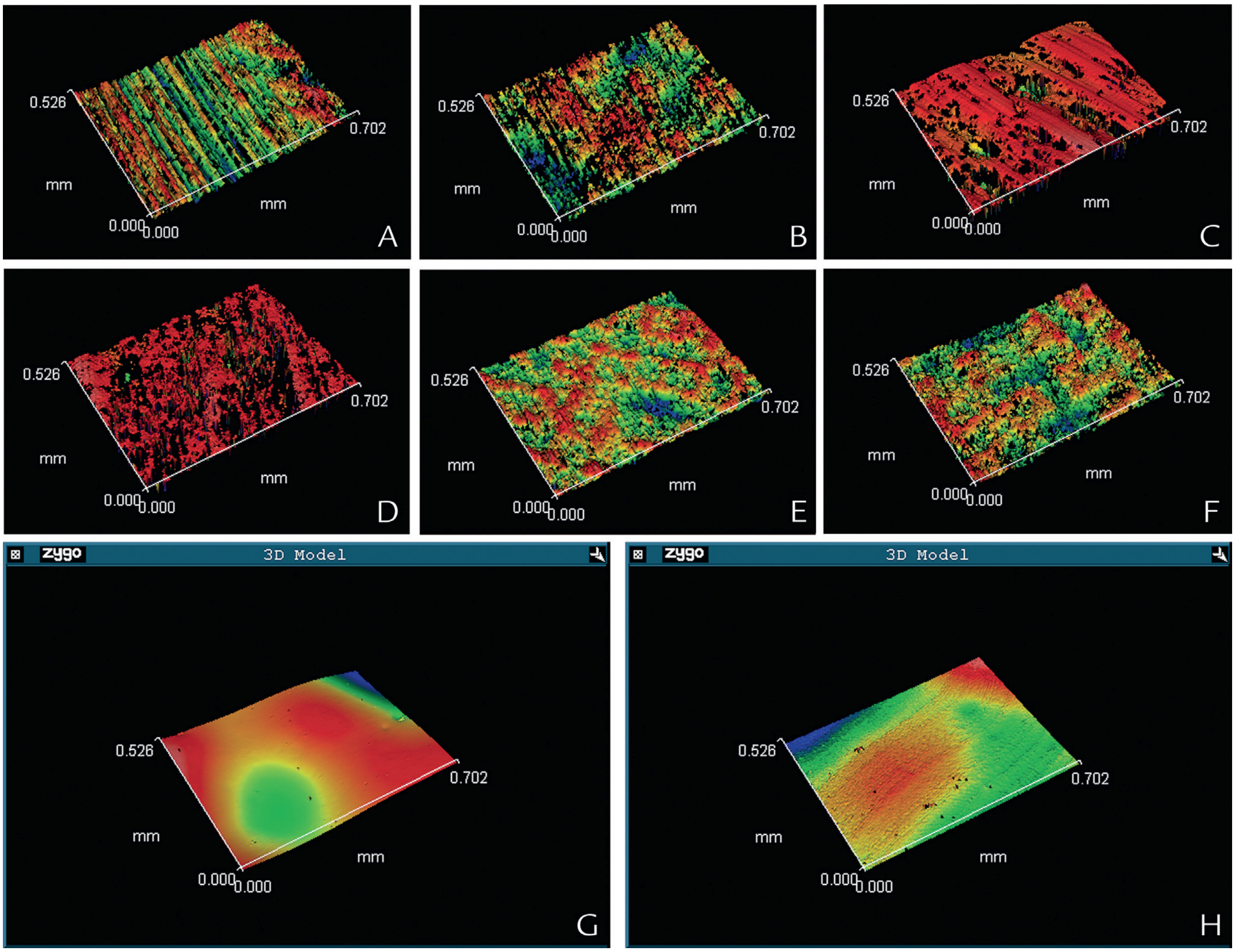


**Figure 1.** Representative surface topography of zirconia specimens scanned by optical interferometer. A, Ground surface before aging (scratches throughout surface parallel to grinding direction). B, Ground surface after aging (more pores and deeper grooves). C, Surface polished using Brasseler kit before aging (smooth areas with scattered scratches and pores). D, Surface polished with Brasseler kit after aging (more pores and projections). E, Surface polished with Komet kit before aging (some irregularities and some scratches). F, Surface polished with Komet kit after aging (more irregularities and corrugations). G, Glazed surface before aging (smooth and homogeneous surface). H, Glazed surface after aging (more undulated and disrupted appearance).

in comparison with the other 3 groups, which were not significantly different from each other ($P$>.05). The results of Ra1 (roughness at the beginning of the study) were comparable with each other across groups and were not significantly different ($P$=.110). However, the mean values of Ra2 (after grinding and polishing) were significantly different between the groups ($P$<.001).

Mean values of Ra1 μm, Ra2 μm, and Ra3 μm were compared with each other for each group to determine the roughness changes before and after surface treatment (grinding and polishing as designed for groups G, GPB, and GPK) and after aging (all groups) (Table 1). For groups G and GPB, roughness changed significantly after surface treatment ($P$<.001 for group G and $P$=.010 for group GPB) and after aging ($P$<.001 for group G and $P$=.009 for group GPB). However, the roughness changes after polishing and after aging were not statistically significant within group GPK ($P$=.140). Also, group C showed no statistically significant changes in Ra before and after aging ($P$=.180).

Surface images were captured by the interferometer for all specimens after the surface treatment received by each group and after aging (Fig. 1). Images of group G specimens showed scratches parallel to the grinding direction throughout the surface (Fig. 1A). After aging, these specimens showed obvious changes in their surface topography, with more pores and deeper grooves (Fig. 1B). Images of group GPB specimens showed some smooth areas with scattered scratches and pores (Fig. 1C). After the same specimens were exposed to aging, they showed less homogenous surfaces, with increased pores and projections (Fig. 1D). Images of group GPK specimens showed some irregularities and some scratches (Fig. 1E). More irregularities and corrugations were detected after the specimens' aging

**Table 2.** Mean ±SD biaxial flexural strength values (MPa)

| Group | Mean | ±SD |
|---|---|---|
| G (grinding) | 879.01 | 157.99 |
| GPB (polishing with Brasseler) | 940.12 | 130.10 |
| GPK (polishing with Komet) | 962.40 | 113.84 |
| C (glazed control) | 956.40 | 150.26 |

Comparison of 4 groups, $P$=.490.

(Fig. 1F). Group C images were smooth and homogenous (Fig. 1G). After aging, these specimens were more undulated and disrupted and can be described as having a melted appearance (Fig. 1H).

Means and standard deviations of biaxial flexural strength (MPa) for all groups are presented in Table 2. Group G showed the lowest mean value of flexural strength, while group GPK recorded the highest mean value. However, ANOVA tests revealed no statistically significant difference of flexural strengths among the groups ($P$=.490).

The Pearson correlation was used to evaluate the association between roughness and flexural strength for each group individually and for all specimens overall. The study showed no statistically significant correlation between the 2 variables ($P$>.05).

## DISCUSSION

This in vitro study was conducted primarily to investigate the effect of grinding and polishing on the roughness of zirconia. Previous studies support our findings regarding the effect of grinding on roughness.[7,27-29] The present study also found that polishing results in roughness statistically comparable to glazing. Results showed that group GPK had almost the same roughness as group C, the glazed control group, which is in accordance with other results that confirmed that the roughness of polished and glazed zirconia are not significantly different from each other.[7,28] The amount and pattern of surface roughness varies among different studies, which can be explained by using different grinding and polishing protocols and different systems to measure surface roughness. For our study, a 3D optical interferometer was used to provide more comprehensive 3D data by noncontact scanning for a standardized surface area. The 3D optical interferometer gives overall information about the pattern and morphology. The current study found that the Ra3 of groups G and GPB were significantly increased compared with Ra2, whereas groups GPK and C did not show any significant change in roughness after aging. Before aging, group GPB was rougher than groups GPK and C. In other words, rough surfaces are more prone to the negative effect of aging than smooth surfaces. Rough surfaces have more residual stresses and pulled grains that can be easily detached, which may explain the higher susceptibility of rough surfaces to hydrothermal degradation.

According to this study, no statistically significant differences in biaxial flexural strength were found among the groups and the lowest mean value was more than 500 MPa, which exceeds the average occlusal load.[10] Our study did not show any correlation between the roughness and flexural strength of zirconia, which agrees with previous studies.[26,30] However, a stronger correlation can be found if cracks formed by grinding travel deeper than surface flaws.[26] In other words, surface defects created by grinding in the present study only affected the superficial layer of the material. Thus, no significant deterioration of zirconia's mechanical properties was detected.

This study showed that proper polishing reduces roughness. Also, polishing minimizes the susceptibility for aging that can be further accelerated by the higher roughness of zirconia restorations. However, limitations include the study's in vitro design, which did not evaluate the influence of the complex factors present in the oral cavity, such as dynamic occlusal load, neuromuscular forces, abrasive food, and parafunctional habits. Furthermore, the study only tested 1 brand of zirconia. Different zirconia brands may have different grain sizes, which can affect the zirconia's transformation toughness and vulnerability to aging.[31]

Future studies should compare the roughness and flexural strength of different brands of monolithic zirconia considering the effect and interaction of other factors such as cyclic loading and providing more information on the composition, grain size, and microstructure of these different materials. Also, the monoclinic content should be quantified using X-ray diffraction analysis to obtain information on phase transformation during aging.

## CONCLUSIONS

Based on the results of this in vitro study, the following conclusions were drawn:

1. Grinding significantly increases the roughness of zirconia, whereas appropriate polishing can result in smooth restorations comparable with glazed surfaces.
2. Rough zirconia is more prone to the negative influence of aging, whereas smooth, polished and glazed surfaces showed some morphological changes after aging; however, this result was not statistically significant when compared with baseline roughness.
3. Ground zirconia presented the lowest biaxial flexural strength. However, grinding and polishing had no significant effect on flexural strength.
4. No significant correlation was found between the roughness and flexural strength of zirconia.

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