Flexural Strength of Monolithic Zirconia after Different Surface Treatments

Hamid Neshandar Asli¹, Samiyeh Rahimabadi², Mehran Falahchai³

ABSTRACT

Aim: The purpose of this study was to evaluate the effect of grinding, over-glazing, reglazing, and polishing on flexural strength of monolithic zirconia.

Materials and methods: In this in vitro study, 50 bar-shaped zirconia specimens were fabricated and divided into 5 groups (n = 10) of no-treatment control group (C), grinding (G), grinding + glazing (GGl), grinding + glazing + grinding (GGlG), and grinding + glazing + grinding + polishing (GGlGp). A universal testing machine was used to measure the flexural strength. Data were analyzed using the Tukey's HSD test and ANOVA (p < 0.05).

Results: There were significant differences between group C and other groups (p < 0.001). Group C showed the highest mean flexural strength among all groups. There was also a significant difference between groups GGlG and GGlGp (p = 0.031), and the latter group showed higher mean flexural strength. There was no significant difference between other groups (p > 0.001).

Conclusion: Reglazing does not have a significant effect on flexural strength of monolithic zirconia compared with grinding. Glazing slightly decreased the flexural strength of ground zirconia surfaces, which was not statistically significant. Polishing improved the flexural strength of ground zirconia surfaces; however, their mean flexural strength was significantly lower than that of the control group.

Clinical significance: Grinding may lead to significant strength reduction and decrease the durability of zirconia restorations. Therefore, polishing of ground surfaces is suggested while glazing has an adverse effect on the strength.

Keywords: Ceramics, Crowns, Dental materials, Dental polishing, Dental porcelain, Surface properties.


INTRODUCTION

Although metal-ceramic restorations are the gold standard for restoration of teeth, demand for higher esthetics has led to the popularity of metal-free restorations.¹ Since the introduction of ceramics, dental ceramic materials have been widely developed and used due to their optimal esthetic properties, high fracture strength, and optimal biocompatibility.²⁻⁴

Polycrystalline ceramics such as zirconium dioxide (zirconia, ZrO₂) have superior mechanical strength as frameworks of fixed dental prostheses and implant abutments.¹⁻² Nowadays, two forms of zirconia restorations are used namely zirconia veneered with porcelain (bi-layered) and full-contour zirconia (monolithic).⁵ Several advantages such as high flexural strength and fracture toughness, desirable optical properties, and good biocompatibility have made zirconia a suitable load-bearing core structure in crowns and bridges.⁶⁻⁷ However, bi-layered zirconia has disadvantages such as chipping of the veneering that occurs more frequently in fixed dental prostheses. The veneering also increases the risk of wear of the antagonistic teeth.⁸ To overcome these complications, monolithic zirconia was introduced and became popular due to favorable characteristics such as requiring less tooth preparation, having higher strength, causing less wear of the opposing teeth, and applicability in patients with parafunctional habits such as clenching and bruxism or in cases with limited interocclusal space.⁹⁻¹¹

Despite the recent developments in the computer-aided design/computer-aided manufacturing technology, occlusal adjustment is still required at the time of delivery. Many studies have investigated the effect of grinding on flexural strength of monolithic zirconia. However, there is still controversy in this respect.⁸ Some studies reported that grinding decreased the flexural strength of zirconia¹² while some others reported an increase in the mean flexural strength after grinding.⁸⁻¹³

It should be noted that the rough surface remained after grinding can result in plaque accumulation, gingivitis, and wear of the antagonistic teeth and may lead to restoration failure.⁴⁻⁷,¹⁰ To minimize these complications, ceramic surfaces must be smoothened as much as possible followed by glazing or polishing; however, the most reliable method for this purpose remains a matter of question.⁴

Although some studies have shown that the most acceptable surface in terms of smoothness can be achieved by glazing, repeated firings may have destructive effects on ceramic surfaces and may cause phase transformation. Reglazing also requires several office visits. Thus, if glazing is not feasible, the best next choice is polishing, which can be done in a single visit and also

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helps infection control by eliminating repeated needs for laboratory procedures.\textsuperscript{4,8} Huh et al. compared six zirconia polishing systems and showed that all polishing systems yielded clinically acceptable results.\textsuperscript{16} Moreover, Amaya-Pajares et al. evaluated the effects of polishing on surface roughness of four ceramic materials and showed that all ceramics had smoother surfaces before occlusal adjustment and polishing.\textsuperscript{3}

Flexural strength is one of the main variables often measured to describe the strength of ceramic materials, which can be affected by surface preparation and polishing.\textsuperscript{1,3} There are many methods to assess the flexural strength of ceramic materials. The most commonly used methods include biaxial, 3-point, and 4-point flexural strength tests. The biaxial method shows the highest and the 4-point method shows the lowest flexural strength.\textsuperscript{15}

Information about the effects of regrinding is scarce, and controversy exists regarding the effects of polishing and glazing on flexural strength of monolithic zirconia. Considering the necessity of repeated grinding following occlusal or proximal adjustment especially after cementation and elimination of excess luting cement or after several exposures to bicarbonate phosphate,\textsuperscript{4} this study aimed to assess the effect of grinding, over-glazing, regrinding, and polishing on flexural strength of monolithic zirconia. The null hypothesis was that no differences exist in flexural strength of monolithic zirconia ceramics after the described procedures.

**Materials and Methods**

In this in vitro study, 50 bar-shaped zirconia specimens measuring $20 \times 4$ mm with 2 mm thickness were fabricated from presintered zirconia blanks (Amann Girbach, Koblah, Austria) using a milling machine (Ceramill, Amann Girbach, Koblah, Austria) (Fig. 1A). Then, the specimens were sintered at 1,450°C according to the manufacturer’s instructions. Initially, the actual dimensions of each specimen were measured using a digital caliper (Links, China) (Figs 1B and C) and they were then divided into 5 groups ($n = 10$): of control (C), grinding (G), grinding + glazing (GGl), grinding + glazing + grinding (GGlG), and grinding + glazing + grinding + polishing (GGlGP). Group C was considered as the control group of the study and did not receive any treatment (as-sintered). Group G was ground using a diamond bur (8003.150HP, CeraPro, Edenta, AU/SG, Switzerland). A new bur was used for every five specimens. An area with 5 mm diameter was outlined at the center of each specimen and marked (Fig. 2). For standardization of specimens in the grinding group, a custom-made grinding apparatus was fabricated to mount the specimens. It had two perpendicular planes; a linear guide was attached to the horizontal plane for constant linear forward and backward movement of specimens while the grinding apparatus and a handpiece (Strong, Saeshin, Korea) attached to a digital micromotor (Marathon, Korea) were clamped to the vertical plane, resulting in the contact of specimens with the rotating bur (Fig. 3).

Grinding was performed for 20 seconds at 2-bar pressure in a continuous forward–backward sweeping motion in the designated area. Group GGl was ground as described and glazed according to the manufacturer’s instructions. Group GGlG was ground and glazed as described and reground using a high-speed handpiece clamped to the custom-made apparatus with an intraoral zirconia grinding bur (Predator, Prima Dental, UK) under water coolant for 20 seconds (Fig. 4). A new bur was used for each five specimens. Group GGlGP was ground, glazed, reground, and finally polished. Polishing was performed using a 3-step intraoral zirconia polishing system (3 step zirconia RA, Prima Dental, UK) with a low-speed handpiece and low pressure under water coolant with a sweeping motion. The sweeping motion was in the same direction as the grinding procedure and continued for

![Figs 1A to C: (A) Bar-shaped zirconia specimens; (B and C) Verifying specimen dimensions using a digital caliper](image-url)
30 seconds, and then the specimens were rotated 90 degrees and the sweeping movement was continued perpendicular to the pervious direction for another 30 seconds. Finally, the specimens were ultrasonically cleaned for 10 minutes at room temperature and air-dried.

A universal testing machine (Z050; Zwick/Roell, Germany) was used to measure the flexural strength. The actual dimensions of each specimen were measured using a digital caliper (Links, China). The specimens were placed centrally in a self-aligning fixture. The edges of specimens had 2 mm distance from the fixture, leaving a 16 mm test span (center-to-center between bearers). The load was applied perpendicular to the longitudinal axis of the specimen (1 mm/minute) (Fig. 5). Finally, the flexural strength of specimens was calculated in megapascals (MPa) using the following equation recommended by ISO6872:\(^\text{8,16}\)

\[
M = \frac{3WL}{2bd^2},
\]

where \(W\) is the applied load (N), \(L\) is the test span (mm), \(b\) is the width of specimen (mm), and \(d\) is the thickness of specimen (mm).
null hypothesis. The results of the present study revealed that grinding significantly decreased the flexural strength (p < 0.001). Similarly, İşeri et al. showed that grinding decreased the flexural strength especially in groups ground by a micromotor. It was concluded that lower temperature rise, which occurs in grinding by a handpiece, is responsible for higher maintenance of the monoclinic phase which would result in smaller reduction in flexural strength. In the current study, due to grinding of specimens by a micromotor, the residual monoclinic phase was less, which caused a significant reduction in flexural strength. Contrary to the results of the present study, Mohammadi-Bassir et al. showed that grinding increased the flexural strength of monolithic zirconia. Using high-speed handpiece under water coolant during grinding in their study seems to be responsible for insignificant rise in temperature. Therefore, the temperature was low enough to prevent reverse phase transformation. Moreover, Zucuni et al. stated that the flexural strength was not adversely affected by grinding.

One of the interesting findings of the current study was the effect of glazing procedure on mechanical properties. It was observed that glazing slightly decreased the flexural strength of ground zirconia surfaces, which was not statistically significant (p = 1). Due to the high viscosity and poor wettability of the glaze layer, it may fail to ideally seal the flaws created during grinding. Similarly, Lai et al. revealed that glazing is not necessary and even impairs the strength of super-translucent zirconia. They also pointed to the risk of damaging the brittle glaze layer prior to flexural strength testing. Another factor which may contribute to strength reduction following glazing in such studies is the formation of surface flaws induced by grinding can adversely affect the mechanical properties if they exceed the depth of the surface compressive layer. Such different results may be due to different methodologies of studies, because several factors may influence the effects of grinding on zirconia such as the applied load, the grinding speed, and the grit size. The results of the current study showed that grinding significantly decreased the flexural strength (p < 0.001). Similarly, İşeri et al. showed that grinding decreased the flexural strength especially in groups ground by a micromotor. It was concluded that lower temperature rise, which occurs in grinding by a handpiece, is responsible for higher maintenance of the monoclinic phase which would result in smaller reduction in flexural strength. In the current study, due to grinding of specimens by a micromotor, the residual monoclinic phase was less, which caused a significant reduction in flexural strength. Contrary to the results of the present study, Mohammadi-Bassir et al. showed that grinding increased the flexural strength of monolithic zirconia. Using high-speed handpiece under water coolant during grinding in their study seems to be responsible for insignificant rise in temperature. Therefore, the temperature was low enough to prevent reverse phase transformation. Moreover, Zucuni et al. stated that the flexural strength was not adversely affected by grinding.

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### Table 1: Mean and standard deviation of flexural strength (MPa) in the five experimental groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>567.92 (103)</td>
</tr>
<tr>
<td>G</td>
<td>343.57 (69.25)</td>
</tr>
<tr>
<td>GGl</td>
<td>342.27 (57.59)</td>
</tr>
<tr>
<td>GGlG</td>
<td>265.04 (64.27)</td>
</tr>
<tr>
<td>GGlGP</td>
<td>369.04 (80.89)</td>
</tr>
</tbody>
</table>

SD, standard deviation
C, control; G, grinding; GGl, grinding + glazing; GGlG, grinding + glazing + grinding; GGlGP, grinding + glazing + grinding + polishing

### Table 2: Pairwise comparisons of the groups by the Tukey’s HSD test

<table>
<thead>
<tr>
<th>Group</th>
<th>C</th>
<th>G</th>
<th>GGl</th>
<th>GGlG</th>
<th>GGlGP</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>G</td>
<td>&lt;0.001</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>GGl</td>
<td>&lt;0.001</td>
<td>1</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>GGlG</td>
<td>&lt;0.001</td>
<td>0.167</td>
<td>0.180</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>GGlGP</td>
<td>&lt;0.001</td>
<td>0.945</td>
<td>0.935</td>
<td>0.031</td>
<td>–</td>
</tr>
</tbody>
</table>

SD, standard deviation
C, control; G, grinding; GGl, grinding + glazing; GGlG, grinding + glazing + grinding; GGlGP, grinding + glazing + grinding + polishing

Discussion

This study investigated the effect of grinding, over-glazing, regrinding, and polishing on flexural strength of monolithic zirconia. Based on the results, there were significant differences among the groups, which did not confirm the null hypothesis. In the present study, two types of grinding procedures were used to simulate the clinical setting namely extraoral grinding by a technician before cementation and intraoral grinding by a dentist as needed after cementation. Therefore, a micromotor was used for the initial step of grinding, and a high-speed handpiece was used for regrinding.

A custom-made device was used to standardize the procedures. Previous studies have shown controversial results about the effects of grinding on zirconia. Some studies stated that grinding produced residual surface compressive stress and increased the flexural strength as such. Others suggested that surface flaws induced by grinding can adversely affect the mechanical properties if they exceed the depth of the surface compressive layer. Such different results may be due to different methodologies of studies, because several factors may influence the effects of grinding on zirconia. The significance level was 0.05.

Distribution of data was evaluated using the Shapiro–Wilk and Levene’s tests with respect to 95% confidence interval. Due to the normal distribution of data (Levene’s test = 1.01, p = 0.412), ANOVA and Tukey’s HSD test were applied to compare the mean flexural strength of the five groups by SPSS version 24 (SPSS Inc., Chicago, IL). The significance level was 0.05.

### Results

Table 1 presents the mean and standard deviation of flexural strength. The highest mean flexural strength was recorded in group C and the lowest was found in group GGlGP (Fig. 6). There were significant differences between group C and other groups (p < 0.001), and between group GGlG and group GGlGP (p = 0.031). There was no significant difference between other groups (p > 0.05; Table 2).

![Fig 6: Mean flexural strength of the groups](image)

**Fig 6:** Mean flexural strength of the groups
of bubbles within the glaze layer during mixing and sintering of the glaze material. The thickness of the glaze layer may also play a role in this respect. However, in the current study, it was tried to avoid these errors by following a standard protocol. Contrary to the current study, Chougule et al. demonstrated that glazing improved the flexural strength of zirconia by filling the surface flaws and subsequent blunting of the flaw tips, which was based on the Anusavice's explanation for this phenomenon. Nonetheless, since Y-TZP is polycrystalline, obtaining an appropriate bond between the glaze layer and Y-TZP ceramic is challenging, and it may result in a bi-layer interface. It has been shown that mechanical features are determined by the layer which is under tension (i.e., the glaze layer in this case).

The current results revealed that regrinding slightly decreased the flexural strength of glazed monolithic zirconia, but this reduction was not statistically significant. It may be explained that in the current study, defects created by regrinding affected the superficial layer of specimens. Also, using water as coolant during regrinding prevented the temperature rise. Consequently, no sparks were observed. It can be concluded that lower temperature rise during regrinding resulted in maintenance of monoclinic phase; thus, no significant effect was observed.

In this study, polishing after regrinding significantly increased the mean flexural strength (p = 0.031). Similarly, Aboushelib et al. concluded that polishing increased the strength by eliminating fine surface flaws. Also, Zucun et al. found that polishing improved fatigue behavior of Y-TZP ceramics by decreasing the surface roughness and removing defects induced by grinding. Contrary to the results of this study, Mohammadibassir et al. concluded that polishing does not have a significant effect on flexural strength of monolithic zirconia. They explained it by negligible removal of monoclinic phase in their study. Also, Traini et al. demonstrated that polishing significantly decreased the flexural strength by formation of microcracks. It should be noted that in the current study, polishing was conducted under water coolant, which eliminated the adverse effects of temperature rise. In general, higher surface roughness increases the risk of zirconia aging, and these restorations are exposed to the intraoral environment; therefore, low thermal degradation is the main concern. An adequate polishing can delay the low thermal degradation and thereby increase the survival rate of zirconia restorations.

Further studies on surface roughness and phase transformation are needed to investigate the effects of regrinding and polishing on monolithic zirconia.

**Conclusion**

Within the limitations of the present study, it can be concluded the following:

- Grinding significantly decreased the flexural strength.
- Glazing slightly decreased the flexural strength of ground zirconia surfaces, which was not statistically significant.
- Regrinding of glazed surfaces had no detrimental effect on flexural strength.
- Polishing of reground surfaces significantly increased the flexural strength. However, the mean flexural strength was significantly lower than that of the control group.

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**References**