

Impact of Different Surface Treatments on Zirconia Strength

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Abstract

Background: Intraoral polishing of zirconia surfaces had led to a significant increase in the surface smoothness and flexural strength of zirconia after surface modifications in the try-in procedure; this is a straightforward procedure and does not need any laboratory interventions. **Objectives:** The aim of this study was to evaluate the effect of different surface treatments on yttrium-stabilized zirconia restorations. **Materials and Methods:** In this study, 36 disk-shaped specimens from zirconia blocks were milled using a CAD-CAM machine with 12 mm diameter and 1.4 mm thickness for 27 disks; however, 12 mm diameter and 1.2 mm thickness were used for nine disks as a control group. They were sintered and glazed according to the manufacturer's instructions. The control group (GA) remained untouched, whereas the other specimens were ground with a diamond rotary instrument. The final dimension was 12 mm in diameter and 1.2 ± 0.1 mm in thickness. The disks were divided into three groups: Grinded group (GB) without any additional surface treatment; reglazed group (GC) by adding glaze material; and polished group (GD), polished with an intraoral polishing kit. The specimens were subjected to a biaxial flexural strength (BFS) test. Data were statistically analyzed using one-way analysis of variance and least significant difference (LSD) significant difference tests ($\alpha = 0.05$). **Results:** Descriptive statistics shows that the highest BFS was recorded for the GD followed by GB, and both GA and GC show nearly similar values. The LSD tests revealed that there was a statistically significant difference between GD and GA ($P < 0.05$), GD had significantly increased the BFS value after being polished compared with other groups, and there was a statistically significant difference between GB and GA ($P < 0.05$). However, there was no statistically significant difference between GC and GA ($P = 0.494$). **Conclusion:** Grinding and polishing techniques significantly increased the flexural strength of full-contoured zirconia, whereas reglazing significantly decreased it.

Keywords: Flexural strength, monolithic, surface treatments, zirconia

INTRODUCTION

With the emergence of zirconia in the dental field, there is a need to fill the gap and to limit all-ceramic restorations in the design and applications. Nowadays, high and accurate restorations can be fabricated with the combination of high mechanical properties of zirconia combined with the state-of-the-art computer-aided design/computer-aided machine (CAD/CAM).^[1-3] In order to use zirconia restorations either using zirconia veneered with feldspathic porcelain (ZVP) or monolithic zirconia (MZ).^[4] However, most clinical failures are related to the chipping of the veneering ceramic (adhesive failure).^[5-7] Therefore, as an alternative to zirconia-based dental restorations, monolithic zirconia dental restoratives, the so-called "Full Contour" without covering the veneering porcelain, are becoming popular in the field of dentistry.^[8] "Zirconium

oxide (ZrO₂) is a polymorphic material that has three different physical form (allotropes): the monoclinic phase (m) is stable up to 1170°C where it transforms into the tetragonal phase (t), which is stable up to 2370°C, and the cubic phase (c) exists up to the melting point at 2680°C.^[9] Relatively large volume expansion (3–5%) leads to the development of internal stresses opposing the opening of the crack, therefore acting to increase the resistance of the material to crack propagation."^[10,11] In a ceramic restoration, the glazing process helps to attain a smooth surface and maintains a high shine for a long period of time.

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Submission: 24-Oct-2021

Accepted: 08-Oct-2021

Published: 17-Dec-2021

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How to cite this article: Azeez SM, Salih SA. Impact of different surface treatments on zirconia strength. Med J Babylon 2021;18:387-93.

Access this article online

Quick Response Code:



Website:
www.medjbabylon.org

DOI:
10.4103/MJBL.MJBL_61_21

Sometimes, further surface modifications may be needed before or after the glazed restoration has been permanently cemented to correct minor interferences.^[12-14] The glazed layer may be removed by these additional adjustments and exposure of the underlying rough surface. Unglazed ceramics may increase plaque retention,^[15,16] increase wear on the antagonistic teeth,^[17] and decrease the strength of the ceramic material.^[18,19] However, the effect of grinding and polishing on the mechanical properties and behavior of Y-TZP is unclear. Some studies have stated that grinding associated with surface defects, increasing the risk of failure.^[20-23] However, other studies have concluded that grinding enhances tetragonal to monoclinic phase transformation, triggering a transformation toughening mechanism that improves mechanical properties.^[24,25] The aim of this study was to evaluate the biaxial flexural strength of zirconia after grinding, glazing, and polishing techniques.

MATERIALS AND METHODS

A total of 36 standardized monolithic zirconia disks were constructed from pre-sintered partially yttrium-stabilized zirconium dioxide (Y2O3 3mol %), translucent monolithic zirconia blocks (ICE Zirkon, ZirkonZahn, SRL, Gais/South Tyrol, Italy), using a 5 Milling Axis CAD/CAM machine (ZirkonZahn, Italy). The milling of zirconia disks having 12mm diameter and 1.4mm thickness was conducted for 27 specimens. However, the milling of disks having 12mm diameter and 1.2mm thickness for nine specimens as a control group was done by using the CAD/CAM system [Figure 1]. Next, all specimens were fired at 1,500°C according to the manufacturer's instruction using a sintering furnace (ZIRCONOFEN 600, ZirkonZahn, Italy). Then, the glazing procedure was carried out for all specimens using

glaze material (Vita Akzent*plus, Zahnfabrik, Germany). All specimens were sintered at 930°C according to the manufacturer's instructions. The specimens' dimensions were checked using a digital caliper (Model IP54 aickar, Germany). To stimulate clinical chairside adjustment, all of the specimens ($n = 27$), except the control group ($n = 9$), were subjected to the grinding procedure. Each specimen was kept within a specialized mold, which was held on a dental surveyor (the marked surface from each specimen subjected to grinding), using a coarse diamond straight fissure bur (VerDent, 1434, UE) [Figure 2], attached to a high-speed handpiece on a dental surveyor in a standardized condition; a constant load of 100 g was used. For each specimen, grinding was carried out in a forward and backward motion for 1 min using a water coolant until a dimension of 12 mm diameter and 1.2 ± 0.1 mm thickness of the disks was obtained. After grinding, all specimens were ultrasonically cleaned in distilled water to remove any ZrO₂ residues for 15 min. Then, the grinded specimens were arbitrarily divided into three groups ($n/9$): grinded (GB), reglazed (GC), and polished (GD) groups, according to the different surface treatments. The control group (GA) received no surface treatments. Glazing material was applied on the grinded surfaces of GC specimens using a ceramic



Figure 1: Some of milled zirconia disks

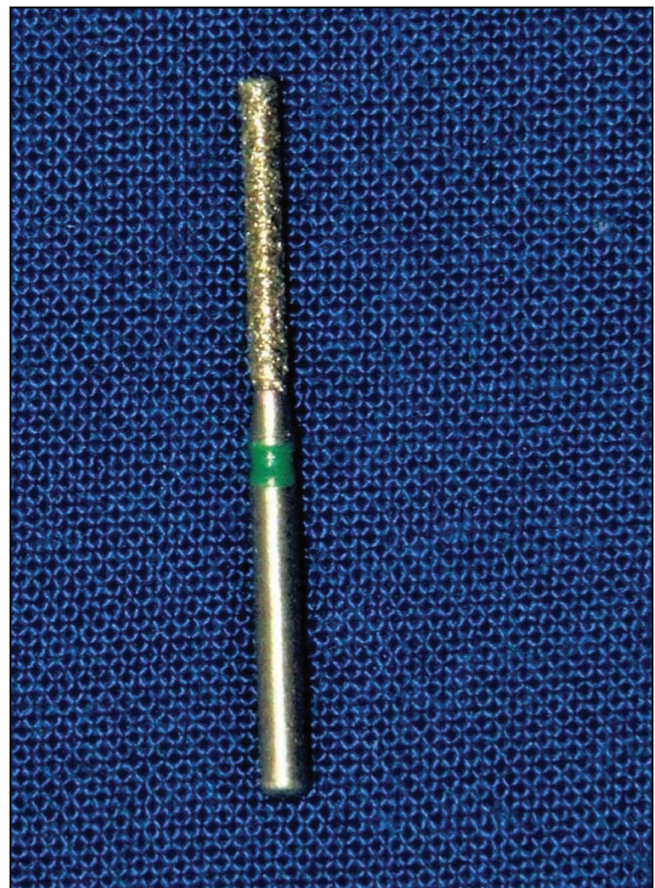


Figure 2: Coarse diamond fissure bur

brush until all glaze material was evenly distributed on the surfaces and fired in a ceramic heating furnace (Programat P300, Ivoclar Vivadent) at 930°C according to the manufacturer's instructions. Two coatings of glaze material were applied. The grinded surfaces of GD specimens were polished by using an intraoral zirconia polishing kit (Kenda Zircovis Diamond, Liechtenstein) [Figure 3] using both blue rubber (medium grit) for 30 s and red rubber (fine grit) for another 30 s, respectively, for all specimens in a sweeping motion forward and backward direction as in the grinding procedure with a low-speed handpiece at 10,000 rpm (EX-203, Japan) [Figure 4]. A new polishing instrument was used for each specimen. Biaxial flexural strength test was carried out by using a universal testing machine (Terco, Sweden) according to the international standard ISO 6872 for dental ceramic materials.^[26] A piston on three balls was used. Three balls with 3.4 mm diameter were used and each were placed at a 120° angle in a symmetrical triangle on a support circle of 10 mm diameter, and they were later attached to the universal testing machine. The flatness and parallelism of the opposing surfaces of each specimen were verified with a digital acceptance within ± 0.05 mm.^[27,28] Each zirconia specimen (diameter 12 mm, height 1.2 mm) was placed centrally on top of three hardened steel balls, and the center of each sample was marked as previously mentioned [Figure 5]. Where only one side of the specimen was treated, the treated side was placed on the tension (bottom) to the testing device. A piston with a flat circular surface of 1.4 mm diameter was used to apply load. The crosshead speed was set at 0.5 mm/min until failure occurred. This means that the treated surface of the specimen experienced tension during the testing. The load to failure (N) of each specimen was recorded using a Pc-aided measurement data recording system for universal material testers, and the flexural strength of the specimens was calculated (MPa) according to the equation recommended by the International Organization for Standardization

(ISO-6872).^[26] Descriptive statistics and one-way analysis of variance analysis of variance were used to compare among groups, and multiple comparisons using post hoc test were used to show the difference between groups. Special software (SPSS, version 3.24) was used. The level of significance was set at $P < 0.05$.

RESULTS

Descriptive statistics shows that the highest flexural strength was recorded for the polished group (BFS = 1,010.2591 mpa) among all the groups, whereas the lowest value was recorded for the reglazed group (BFS = 473.7512 mpa).

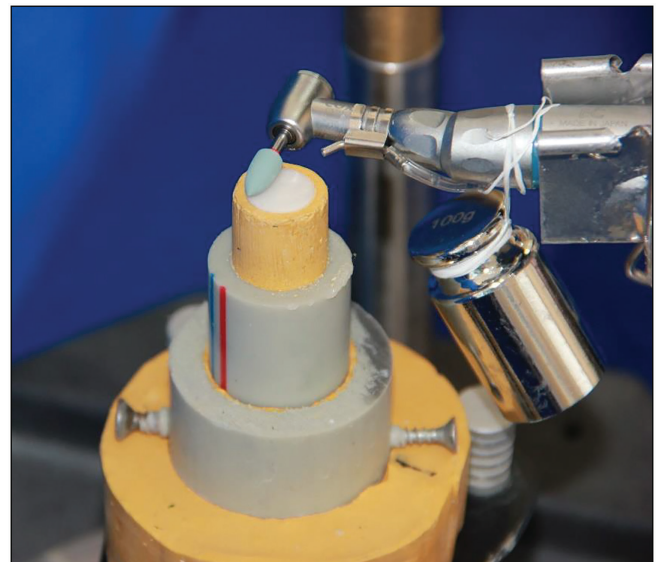


Figure 4: Polishing techniques using zirconia polishing kit



Figure 3: Polishing kit kenda

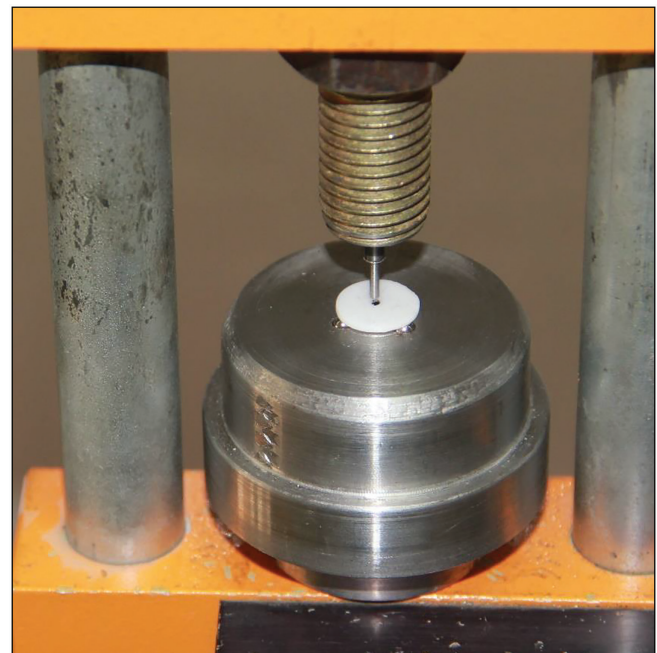


Figure 5: Zirconia disk during flexural strength test

In addition, the value recorded for the grinded group (BFS = 808.4534 mpa) was much higher than the results recorded for the control group (BFS = 522.9721 mpa). The groups that were mechanically surface treated (grinded and polished) showed higher values than the glazed and control group [Table 1].

One-way analysis of variance showed that different surface treatments significantly affected the mean BFS values [Table 2]. The least significant difference (LSD) multiple-comparisons test for all the zirconia groups [Table 3] revealed that there was a statistically significant difference between the polished and control group ($P < 0.05$); this means that the polished group had significantly increased the biaxial flexural strength value after being polished by the zirconia polishing kit compared with other groups. Also, there was a statistically significant difference between grinded and control groups ($P < 0.05$); this means that the grinding and polishing procedures significantly increased zirconia strength.

There was no statistically significant difference between the reglazed and the control group ($P = 0.494$), whereas the mean BFS of the reglazed group was lower than the

mean BFS of the control group. However, there was a statistically significant difference between the reglazed and the polished group ($P < 0.05$), meaning that the BFS of the polished group was higher than the reglazed group.

DISCUSSION

Ceramics material are breakable and weak in tension.^[29] “Flexural strength and fracture toughness measurements are often used to describe the strength of ceramic materials.”^[30] That is why the current study depended on the biaxial flexural strength test. It is a reliable method of choice for studying brittle materials since the highest tensile stress occurs within the central loading area and edge failures are eliminated.^[31] The sizes and shapes of the disks that were used during testing were recommended according to the dimensions stated by ISO 6872, to meet the exact requirements of the biaxial testing protocol.^[32] The standard described that a test piece should have a thickness of 1.2 ± 0.2 mm and a diameter of 12–16 mm. A load of 100 g was used, which is naturally employed by clinicians in grinding and polishing procedures.^[23] In the

Table 1: Mean of biaxial flexural strength (BFS) test for all groups

Groups	N	Minimum	Maximum	Mean	Std. error	Std. deviation	Variance
Control	9	420.84	631.26	522.9721	29.05441	87.16323	7,597.429
Grinded	9	564.81	1,007.80	808.4534	64.01971	192.05913	36,886.708
Reglazed	9	387.61	531.59	473.7512	17.68274	53.04823	2,814.115
Polished	9	631.26	1,207.14	1,010.2591	69.86671	209.60013	43,932.216

Table 2: One-way ANOVA of mean BFS values for all zirconia samples

Biaxial flexural strength	Sum of squares	df	Mean square	F	Sig.
Between groups	1,714,415.987	3	571,471.996	25.056	0.000 *
Within groups	729,843.746	32	22,807.617		
Total	2,444,259.733	35			

ANOVA = analysis of variance, BFS = biaxial flexural strength

*Indicate statistically significant results between groups

Indicate mean difference is significant when P values < 0.05

Table 3: Results of post hoc tests (LSD) showing the mean BFS values of all zirconia samples

	Group		Mean difference	Std. error	Sig.	95% confidence interval	
						Lower bound	Upper bound
LSD	Co/ntrol	Grinded	-285.48126*	71.19241	0.000	-430.4955	-140.4671
		Reglazed	49.22091	71.19241	0.494	-95.7933	194.2351
		Polished	-487.28698*	71.19241	0.000	-632.3012	-342.2728
	Grinded	Reglazed	334.70217*	71.19241	0.000	189.6880	479.7164
		Polished	-201.80572*	71.19241	0.008	-346.8199	-56.7915
	Reglazed	Grinded	-334.70217*	71.19241	0.000	-479.7164	-189.6880
LSD	Polished	Polished	-536.50789*	71.19241	0.000	-681.5221	-391.4937
		Grinded	201.80572*	71.19241	0.008	56.7915	346.8199
		Reglazed	536.50789*	71.19241	0.000	391.4937	681.5221

BFS = biaxial flexural strength, LSD = least significant difference

*Indicate significant differences among groups

current study, to stimulate occlusal adjustments, specimens were roughened with a coarse grit diamond rotary instrument (DRI).^[19,33,34] During grinding and polishing, continuous irrigation was used to prevent the production of heat because some authors have stated that the heat produced from adjusting zirconia may stimulate reverse transformation.^[35] In the present study, specific polishing burs optimized for polishing the zirconia's surface were used because zirconia naturally is much tougher than other dental ceramics and therefore needs specialized equipment for polishing.^[36-38] The polishing procedure took about 30s for each polisher to represent an average amount of time that a clinician would spend on a restoration.^[39,40] The value for Poisson's ratio, which is present in the equation of the biaxial strength test, was assumed as 0.25, because if the value for the ceramic is not known, a Poisson's ratio of 0.25 is used.^[26,41] Grinding creates two counteracting effects on zirconia. First, it led to the formation of residual surface compressive stress, which can increase the mean flexural strength of zirconia.^[42] It has been documented that the mechanical properties of zirconia are affected by the monoclinic particle content, and the tetragonal to monoclinic (t→m) phase transformation is associated with a large volume expansion (3%– 5%) that induces compressive stresses contrasting crack opening and acts to increase resistance to crack propagation.^[43] The second effect of grinding is that it induces surface defects, which may become strength determining if they exceed the depth of grinding-induced surface compressive layers.^[44,45] As long as the flaw size remains the same after grinding, zirconia strength increases with an increase in residual stresses.^[46] However, Kumchai *et al.* stated that excessive compressive residual stresses can lead to lateral crack propagation to the surface of zirconia and this will ultimately cause the material to fail.^[47] In this study, it is shown that adjusting zirconia surface with a diamond bur increases its flexural strength, despite increasing surface roughness of zirconia after grinding.^[48] Adjusting zirconia with a diamond bur increases its flexural strength. This is in agreement with the finding of Mohammadi-Bassir *et al.*, which concluded that grinding with coarse rotary instruments causes an increase in the surface roughness and a significant improvement in the flexural strength.^[34] This may be due to the fact that the flaw size seems not to exceed the thickness of the grinding-induced surface compressive layer after grinding.^[49] In response to crack formation, Y-TZP undergoes transformation toughening, which is achieved by the compression of cracks when tetragonal phase zirconia transforms to the less compact monoclinic phase.^[50,51] The result of the present study is also in agreement with previous studies.^[52-55] However, in the argument, several previous studies have shown that adjusting zirconia with a diamond bur reduces its flexural strength.^[56-58] This may be related to the surface defects that will be produced in response to the grinding, which

can act as an area of stress concentration and may initiate catastrophic failure in zirconia during loading.^[40] In addition, Kosmac *et al.* showed that dry high-speed grinding (diamond grit size 150 µm) lowered the biaxial flexural strength of the zirconia framework material. The authors stated that the decrease in strength could be due to the surface flaws caused by grinding.^[20] Based on the results of the present study, a high-speed grinding with water cooling may not have caused sufficiently deep flaws to exceed the surface compressive stresses as the flexural strength was significantly increased; grinding under water cooling may be advisable for zirconia frameworks in order to make the cutting as efficient as possible and to avoid excessive subsurface damage.^[29] This is due to the fact that grinding under a water coolant can promote the tetragonal (t)/ monoclinic (m) phase transformation, which increases the surface compressive strength.^[44] Although glazing reduces the wear of opposing enamel, the results of this study showed that glazing decreases the strength, and this may be due to the fact that glazing causes cracks in the porcelain and thus decreases flexural strength.^[59] It may also be due to the fact that reheating zirconia after adjustment causes reverse transformation from the monoclinic phase back to the tetragonal phase, releasing the compression and decreasing the strength of the zirconia.^[46] The results showed that glazing significantly decreased the flexural strength for all systems. It is assumed that reverse transformation and/or change in the particle size may have occurred and/or the residual stress layer, which is formed during manufacturing processes, may have been removed from the surface with the heat treatment.^[60] Also, because reglazing must be performed in a dental laboratory with a furnace, it requires multiple office visits. Repeated firings may have a destructive effect on the ceramic surface and can cause phase transformation.^[61] Flinn *et al.* stated that during glazing, zirconia is subjected to firing and moisture, which may affect the flexural strength and make it susceptible to low-temperature degradation.^[62] However, others have reported that glazing increases the strength of the ceramic materials by reducing the depth and/or sharpness of critical flaws.^[63] However, in a study by Kumchai *et al.*, conducted on heat-treated groups to determine whether the glaze-firing cycle had an effect on the flexural strength of zirconia, it was found that in the zirconia samples that were fired with a glazing cycle without glazing materials, there was no significant reduction in its flexural strength compared with the control group. However, the strength reduction was observed in glazed zirconia with glazing materials.^[47] In this study, the polishing of zirconia by using a specialized zirconia polishing kit showed marked improvement in strength; this is due to the fact that the polishing of zirconia reduced the amplitude of scratches and has been shown to improve the flexural strength of adjusted zirconia.^[62] This is in agreement with Fahmy *et al.*, who found that polishing caused a reduction in

initial surface flaws and defects, inhibiting further crack propagation and thus increasing the restoration's resistance to fracture. Moreover, residual compressive strength might be produced by polishing, thereby increasing ceramic surface hardness.^[18] Finishing and polishing with a series of rotary instruments and rubber cups may be an alternative technique but is not used by all clinicians.^[37] Huh *et al.* compared the effectiveness of six zirconia polishing systems and showed that all polishing systems yielded clinically acceptable results.^[64] The ceramic polishing kits ensure surface smoothness, durable outcome, and cost effectiveness.^[33,50,65] In addition, polishing is a straightforward procedure.^[19]

CONCLUSION

Grinding causes a significant decrease in the surface smoothness of zirconia, but the flexural strength is significantly increased; however, the polishing procedure on zirconia increases surface smoothness and flexural strength significantly. Reglazing can restore surface smoothness, but it decreases the flexural strength of zirconia.

Acknowledgments

The authors thank Kenda polishing dental kit company for their materials, New Dent company for their support in terms of dental burs and handpieces, and Smart Art Lab for their CAD/CAM supports.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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