EGYPTIAN DENTAL JOURNAL
www.eda-egypt.org

Vol. 69, 497:504, January, 2023

Print ISSN 0070-9484 • Online ISSN 2090-2360

Fixed Prosthodontics and Dental Materials

Submit Date : 21-10-2022 • Accept Date : 22-11-2022 • Available online: 1-1-2023 • DOI : 10.21608/edj.2022.168243.2288

THE EFFECT OF SURFACE GRINDING AND FINISHING ON THE SURFACE ROUGHNESS AND FLEXURAL STRENGTH OF CUBIC ZIRCONIA

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ABSTRACT

Statement of problem: The translucency of cubic zirconia is improved on the expense of its strength. The effect of grinding and finishing on its mechanical properties is still unclear.

Purpose: The aim of this study was to evaluate the influence of glazing and polishing protocols on the surface roughness and flexural strength of monolithic cubic zirconia after dry and wet grinding.

Materials and methods: Super translucent multilayer zirconia (STML) disks were cut, sintered, and glazed according to the manufacturer's recommendations. Samples were randomly divided into three groups according to surface grinding: Group (C): control (no grinding-as glazed), Group (D)grinding under dry condition and group (W) grinding under wet condition. Each group of (D)and(W) was subdivided into two subgroups according to surface finishing whether glazing or polishing. The roughness average (Ra) was measured using contact profilometer. Biaxial flexural strength test was done using a universal testing machine. Statistical analysis was performed.

Results: The glazing showed a statistically significantly higher mean Ra ($P<0.05$) than polishing whether after wet or dry grinding. The dry ground groups showed a statistically significantly higher mean Ra ($P<0.05$) than wet ground groups. The glazing showed a statistically significantly lower mean biaxial flexural strength than Polishing ($P<0.05$) after dry grinding. While there was no statistically significant difference between glazing and polishing ($P>0.05$) after wet grinding.

Conclusion: Adequate polishing can produce a smoother surface than reglazing. Dry grinding can increase the surface roughness to a degree that can affect the flexural strength of STML zirconia.

KEYWORDS: Cubic zirconia, grinding, glazing, polishing, surface roughness, flexural strength.

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INTRODUCTION

Excellent mechanical strength and biocompatibility of monolithic zirconia made it recently one of the most used materials in dental prosthetic clinics for its advantage of eliminating veneering porcelain chipping proplem.[1,2] Generally, Zirconia is a poly-crystalline ceramic that exists as three crystalline phases: monoclinic, tetragonal and cubic.[3] Conventional zirconia, 3Y-TZP (3 mol % Yttrium-stabilized tetragonal zirconia) is an opaque white material due to the high refractive index of tetragonal phase which leads to scattering of the light from grain boundaries.[4] One of the strategies have been used to improve its translucency is increasing the yttria content to 4 mol % (4Y-PSZ) or 5 mol % (5Y-PSZ) and a cubic-to-tetragonal weight ratio of up to 75% resulted in the third generation of zirconia, with high translucency and lower fracture resistance compared to previous generations. These characteristics allowed this generation of zirconia to be widely used in front teeth. [4,5]

To simulate natural teeth, an innovative multi-layered translucent zirconia material with a natural gradation in translucency has recently launched in the dental market. The multi-layered zirconia has varying color saturations in different layers but identical Y_2O_3 content throughout all layers.[6,7]

Clinical adjustments of zirconia restoration are essential for occlusion and emergence profile when the restoration shows premature contact or improper contour.[8,9] Diamond burs which are used for chairside adjustment can lead to the removal of the glaze layer and loss of surface smoothness leaving a defective surface. [10]The resulting surface roughness and imperfections may lead to wear of opposing enamel, plaque accumulation and color staining. [11–13] Major adjustments can produce deep surface flaws and micro-cracks which may increase and propagate a decrease in the flexural strength.[14–16]

Even though glazing is a common manner for regaining high-gloss surface ceramics, previous studies showed a decrease in the strength and fracture toughness of these ceramics. [5,16,17] On the other hand, polishing is one of the most used methods that produce restorations with better surface morphological characteristics as well as resistance to fracture.[18–20] Polishing systems, unlike glazing, do not apply an additive layer to the monolithic zirconia restoration's surface, but instead remove the material by abrasion, resulting in a reduction in surface roughness.[21–23]

The impact of grinding and finishing on the surface roughness and flexural strength of cubic zirconia restorations is variable. Therefore, the aim of this study was to evaluate the influence of glazing and polishing protocols on the surface roughness and flexural strength of cubic zirconia after dry and wet grinding. The null hypothesis was that no differences would be found between polished and glazed groups after dry and wet grinding.

MATERIALS AND METHODS

Sample size calculation

Sample size detection was performed using G*Power Version 3.1.9.2. The analysis used surface roughness using profilometry as the primary outcome. The effect sizes f = (0.715) was calculated based on the results of Silva FP et al (2019).[24] Using alpha (α) level of (5%), Beta (β) level of (20%) i.e. power = 80% and standard deviation within each group = 0.3; the minimum estimated sample size was 8 samples per group.

Sample classification

Forty samples were randomly divided into 3 groups according to the surface grinding: Group (C): control (no grinding-as glazed) (n=8), Group (D)grinding under dry condition (n=16) and group (w) grinding under wet condition (n=16). Groups (D) and (W) were subdivided into two subgroups according to the surface finishing method into Subgroup (DG): glazed after dry grinding (n=8), subgroup (DP)polished after dry grinding (n=8), subgroup (WG)Glazed after wet grinding (n=8) and subgroup (WP) polished after wet grinding (n=8).

Specimen preparation

A pre-sintered Super Translucent Multilayered STML zirconia blank (kuraray Noritake Dental Inc Tokyo, Japan) was used. Its Chemical composition is: 88-90% zirconium oxide, 7-10% Yttrium oxide, <3% Hafnium oxide and 2% other oxides. A total of 40 discs of STML were prepared using Isomet sawing machine (Buchler Isomet diamond saw 4000, Buchler), with disc dimensions of 14.4 mm diameter and 1.44 thickness. Specimens were then sintered in a furnace (inFire HTC speed furnace, Sirona, Bensheim, Germany) at 1550°C for 2 hours of holding time and a heating rate of 10˚C/minute. All specimens were put into an ultrasonic water bath (Easycleaner Medical Trading,USA) for cleaning for 10 min. A digital caliper (Model 01407A; Neiko) was used to check the thickness and diameter of each specimen to be 1.2 mm thick and 12 mm diameter after sintering. Each specimen was glazed using the Dentsply universal overglaze (Dentsply Sirona Inc. North Carolina, USA), following the manufacturer firing recommendations. The glaze was mixed in Its jar thoroughly with a spatula. A thin layer of the overglaze (Dentsply Sirona Inc. North Carolina, USA) was applied all over the specimens using a staining brush size 6. Each specimen was vibrated manually until the surface was covered uniformly, allowed to dry then fired in the furnace (MultiMate ntx press, Dentsply Sirona, USA) used at 820^{o}C.

Grinding

A specially designed device **Fig.1**, consisting of two parts was used in the grinding process. A round-end cylinder-shaped diamond bur for zirconia (D. Z856-F.FG Frank. Dental Inc. Gmund, Germany) was fixed in the high-speed handpiece (T3 contra-angle high speed handpiece, Dentsply Sirona, Germany) for grinding the specimens. The device was designed to make the diamond bur in intimate contact with the sample with constant pressure. The grinding process was done by the same operator who pressed on the foot control to its maximum limit. Then, the sample was rotated by the operator in an anticlockwise direction for 30 seconds. The diamond bur was changed every 4 samples with a new one to maintain similar cutting efficiency.[10] The thickness of the removed layer (80-100μm) was verified using a digital caliper (Model 01407A; Neiko). The (D) group was ground under dry conditions (The coolant was off) while the (W) group was ground under wet conditions.

Reglazing

(DG) and (WG) subgroups were reglazed in the same manner as the previously mentioned technique of glazing.

Polishing

Zirconia three steps polishing kit (ZiL MASTER-shofu) was used for polishing the specimens of (DP) and (WP) subgroups.

Twenty strokes over a period of 30 s were done per step of polishing. Polishing was performed by the same operator in one direction using a low-speed hand piece (FX25 low-speed handpiece,

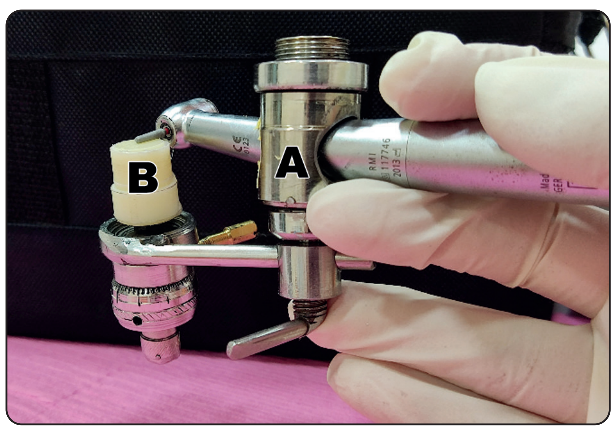

Fig. (1): (a) The first part for holding the high-speed handpiece to be fixed during the grinding,(b) the second part was a teflon mold for holding the sample and can be rotated around its long axis.

NSK, Japan). The zirconia polishing kit was used following the manufacturer instructions with speed range (10,000) and in three steps according to the impregnated diamond coarseness (coarse polisher for 30s, medium polisher for 30s then fine polisher for 30s)

Measurements

The surface topography was assessed quantitatively by measuring the average surface roughness of the discs. The surface roughness of the different discs was recorded using the stylus profilometer (Mitutoyo Japan SJ-210). Surface roughness values were determined for each disc in 3 areas near the center of the specimen then the average was calculated.

Specimens were subjected to biaxial flexure strength test according to ISO 6872.[25] Using a universal testing machine(model 5566;instron Corp), the maximum compressive load was measured in N. Each specimen was put on a cylindrical fixture with three support balls that were equally spaced. The specimens were subjected to a progressive load (0.5 mm/min) using a flat circular tungsten piston (Ø=1.4 mm).

Statistical analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). All data showed parametric (normal) distribution. Data were presented as mean and standard deviation (SD) values. Two-way ANOVA test was used to study the effect of surface finishing, surface grinding as well as their interactions on biaxial flexural strength and surface roughness. Bonferroni's post-hoc test was used for pair-wise comparisons when ANOVA test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY:IBM Corp.

RESULTS

surface roughness

Two-way ANOVA test for comparison between surface roughness Ra of surface finishing techniques with each surface grinding technique showed that with dry as well as wet grinding; there was a statistically significant difference between surface finishing (*P*-value = 0.005, Effect size = 0.2) and (*P*-value = 0.002, Effect size = 0.253), respectively as displayed in table (1). Pair-wise comparisons between surface finishing techniques revealed that reglazing showed the statistically significantly highest mean Ra. Polishing showed statistically significantly lower mean Ra. Control group showed the statistically significantly lowest mean Ra. as displayed in table (1)

TABLE (1). The mean, standard deviation (SD) values and comparison between Ra (μm) of surface finishing techniques.

Surface grinding	Control		Reglazing		Polishing		*P*-value
	Mean	SD	Mean	SD	Mean	SD	
Dry grinding	0.324^{Cf}	0.058	0.856^{AD}	0.072	0.74^{BD}	0.084	0.005*
Wet grinding	0.324^{Cf}	0.058	0.707^{AE}	0.075	0.573^{BE}	0.095	0.002*
P-value				0.001*		<0.001*	

: Significant at P ≤ 0.05

TABLE (2) The mean, standard deviation (SD) values and comparison between biaxial flexural strength (MPa) of surface finishing techniques.

Surface grinding	Control		Reglazing		Polishing		*P*-value
	Mean	SD	Mean	SD	Mean	SD	
Dry grinding	703.7 ^{A}	77	507 ^{C}	29.4	616.5 ^{B}	103	0.006*
Wet grinding	703.7	77	578.5	55.6	630.2	82	0.171
P-value				0.062		0.713	

: Significant at P ≤ 0.05

Biaxial flexural strength.

With dry grinding, there was a statistically significant difference between surface finishing techniques (*P*-value = 0.006, Effect size = 0.2). Pair-wise comparisons between surface finishing techniques revealed that control group showed the statistically significantly highest mean biaxial flexural strength. Polishing showed statistically significantly lower mean biaxial flexural strength. Reglazing showed the statistically significantly lowest mean biaxial flexural strength. While with wet grinding; there was no statistically significant difference between surface finishing techniques (*P*-value = 0.171, Effect size = 0.053) as displayed in table (2).

DISCUSSION

Recently, the (Y-TZP) material has undergone microstructure and composition modifications to improve translucency. One of these modifications was increasing yttrium oxide above 4% by mol (<10% by weight) and introducing nonbirefringent isotropic cubic phase zirconia [18]. Cubic zirconia does not have the capability to perform (t→m) phase transformation as tetragonal zirconia, therefore, while the translucency was significantly improved, the strength and toughness were significantly diminished. [4]

Cubic zirconia may be affected by grinding and finishing more than the previous generations. The aim of this study was to evaluate the influence of reglazing and polishing protocols on the strength of monolithic cubic zirconia after dry and wet grinding.

In the present study, the null hypothesis was rejected. Regarding surface roughness, there was a significant difference observed between the different finishing techniques. Whether with dry or wet grinding, reglazing showed a statistically significantly higher mean roughness than Polishing. This may be attributed to different smoothing strategies between polishing and glazing. Polishing can remove a variety of defects and flaws from the ground surface, resulting in uniform particles and lowered roughness.[20] The glaze layer created by applying a low-fusing glass cover porosities and microcracks on the ceramics, and reduces the depth and sharpness of surface cracks without completely removing them.[20] The results of the current study agreed with the study made by **Freitas et al.**[1] who found that the results of average surface roughness of polished samples of Y-TZP monolithic zirconia were less than that obtained by glazed samples. Also, **Vila-Nova et al**[18] found that glazed groups of 5Y-TZP showed a higher roughness than the rubber-polished groups.

A number of previous studies observed that polishing resulted in similar surface roughness as reglazing.[4,23,26] **Sarac et al**[13] concluded that the smoothness produced by the porcelain adjustment kit was equivalent to the glazed specimens. In the current study, in contrast to the previous studies, it was revealed that the polishing process produced smoother surfaces than the reglazing technique. These differences between studies may be attributed to using different polishing protocols and differences in the polishing time. Many studies have shown that polishing kits designed specifically for zirconia produce better results than standard kits because they have a primary abrasive that is effective for the zirconia's high hardness and consists of diamonds and other abrasives like SiC and Al_2O_2.[19,22]

In this study, dry grinding showed statistically significant higher mean Ra than Wet grinding. This can be explained by the uncontrolled heat obtained during the dry grinding which created a lot of cracks and excessive roughness on the surface.[27] These results were in agreement with **Albishry et al**[9] who proved that surface adjustment with dry grinding conditions increased the surface roughness of Y-TZP when compared to wet conditions.

The lowest Ra values were found in the group not subjected to any grinding or finishing. These findings were in agreement with **Pajares et al**[12] who found that the baseline values of all ceramic materials used showed lower surface roughness than values obtained after grinding and polishing.

Regarding the biaxial Flexural strength, all ground groups showed a decrease in biaxial flexural strength in comparison to the control unground group. This decrease was statistically significant in groups ground under dry conditions and statistically non-significant in groups ground under wet conditions but still numerically show a decrease in their strength compared to control groups. The decrease in flexural strength can be justified by using diamond burs during grinding which can cause surface flaws, structural defects and create microcracks. These microcracks can propagate into the material resulting in deterioration of its mechanical properties.[18]This was in accordance with several studies that proved that fractures in zirconium oxide restorations occur in the superficial/subsurface areas, and it has been observed that occlusal adjustment procedures can cause crack initiation and propagation, affecting the strength of the ceramics.[2,15] **Hatanaka et al.**[5] found that grinding reduced the strength of 5Y-TZP significantly and this was linked to this material which is not prone to t/m transformation. However, **Souza et al**[3] reported an increase in the flexural strength of conventional zirconia after grinding. This difference can be explained by using zirconia material with different compositions and different microstructures. In the present study, we used super translucent multilayer cubic zirconia, this material has up to 10% by weight yttria content to stabilize the cubic grains.[7] Thus, this material is not prone to t/m transformation and toughening cannot occur.[7]

Concerning the effect of finishing on flexural strength, the glazed groups ground under dry conditions showed a statistically significantly lower mean biaxial flexural strength than polished groups ground under dry conditions. This could be explained by the negative correlation present between the surface roughness and flexural strength.[4]These results were in agreement with those of **Kumchai et al**[28] and **Hatanaka et al** [5] who found that reglazing upon grinding reduced the strength of monolithic zirconia, whereas polishing yielded the best mechanical strength. Moreover, numerous studies have found that glazing somehow cannot improve flexural strength.[16,17,28]

On the other hand, there was no statistically significant difference found between reglazing and polishing in groups ground under wet conditions. This can be explained by the water-cooling effect during grinding reduce the uncontrolled heat obtained during the dry grinding which can create a lot of cracks and excessive roughness on the surface.[27,29]This was in accordance with **Albishry et**

al[9] who found that dry grinding increased roughness and decrease the flexural strength compared to wet grinding.

It's worth mentioning that the lowest mean biaxial flexural strength in this study was still above 500 MPa, which is within the normal occlusal load and regarded clinically acceptable.[4]

One of the limitations of the present study was being an in vitro study that did not take into consideration other factors present in the patient mouth like neuro-muscular forces, occlusal load and aggressive food. Furthermore, the study only tested one brand of zirconia. Future studies are needed to compare the roughness and flexural strength of different brands of monolithic zirconia considering the effect and interaction of other factors such as cyclic loading.

CONCLUSION

Under the circumstances of this study, it can be concluded that:

- Adequate polishing of STML zirconia can produce a smoother surface than reglazing.
- Dry grinding can increase the surface roughness to a degree that can affect the flexural strength of STML zirconia.
- The flexural strength in all specimens after different grinding and finishing techniques showed more than 500MPa which was clinically acceptable.

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