Strength of a Zirconia-Reinforced Glass-Ceramic After Diamond Bur Adjustment

Keywords

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ABSTRACT

Introduction: Adjustments with diamond burs on the ceramic surface can affect its roughness and decrease flexural strength. This study evaluated the effect of polishing or glazing on the surface roughness and biaxial flexural strength of a zirconia-reinforced lithium silicate glass-ceramic upon adjustment with diamond burs. Methods: Seventy disks were prepared according to ISO 6872 and divided into seven groups (n = 10) according to different adjustments and finishing processes. Surface roughness was measured prior to biaxial flexural strength testing. The topography was analyzed using an atomic force microscope , fracture markings were identified using a stereomicroscope and representative specimens were analyzed using scanning electron microscopy. Results: The use of diamond burs significantly increased the surface roughness and decreased the strength of the evaluated ceramic (p<0.05). Polishing reduced the ceramic's roughness but resulted in flexural strength similar to that of the groups with wear (p>0.05). The glaze-treated specimens showed flexural strength statistically similar to the control group (p>0.05) but higher roughness, similar to those with wear. Conclusions: Polishing reduced the surface roughness but did not affect the biaxial flexural strength of the ZLS ceramic. At the same time, the application of glaze after wear increased the strength.

INTRODUCTION

Reinforced dental ceramics are becoming popular due to their dual properties of superior esthetics and flexural strength. Occlusal adjustment with diamond burs is a common clinical practice to improve function. Still, it can produce defects on the surface that can make it rough and propagate at a microscopic level, which can adversely affect the strength of the material.[1-3]

The glaze, which consists of a transparent, viscous, low-melting material, is applied to the ceramic surface, followed by a new firing cycle, which has been used to obtain a smooth and glossy finish. This smooth outer layer seals the surface defects, thereby increasing the strength of the ceramic.[3-7] When the occlusal adjustment is performed, the glaze tends to be removed, and the exposed surface is smoothened out by polishing with polishing kits that contain abrasive rubbers.[2] This is an effective technique to reduce surface defects but cannot remove them entirely. Studies have reported that smoother surfaces are generated by polishing rather than by the re-application of glaze.[2,6,7] In these cases, the granulation of the diamond bur used is a factor to be considered. The use of FF burs in conjunction with abrasive burs and diamond paste can result in a smooth surface with similar roughness to that obtained with glaze.[8]

The ceramic composition is also a factor to consider since the surface roughness may depend on the type and number of crystals present in the microstructure.[8] A study carried out on zirconia reported that high surface roughness did not reduce the material's strength. This fact was attributed to the phase transformation from tetragonal to monoclinic that occurs within this type of material when subjected to stresses caused by the use of diamond burs.[9]

The zirconia-reinforced lithium silicate glass-ceramic (ZLS) ceramic is composed of very fine lithium metasilicate and lithium disilicate crystals with a glassy matrix containing zirconium oxide grains. It is important to evaluate if the presence of irregularities on the surface decreases the biaxial flexural strength and if the polishing or glazing could reduce these irregularities and increase the glass-ceramic strength. The objective of the study was to test the following hypotheses: 1) lower surface roughness results in higher flexural strength, 2) polishing or application of glaze after adjustment does not increase the surface roughness and reduce the strength of the composite ceramic, and 3) the type of diamond bur (F or FF) used for adjustment does not reduce the flexural strength.

MATERIALS AND METHODS

SPECIMEN PREPARATION

A circular metallic holder was glued on the top surfaces of ten zirconia reinforced-lithium silicate (ZLS) glass-ceramic blocks (18×14×12 mm^3, Vita Suprinity, Vita Zahnfabrik, Bad Säckingen, Germany). The blocks were reshaped to form a 12 mm diameter cylinder using a silicon carbide abrasive sandpaper of #120 Grit using the Struers equipment (Sultrade, São Paulo, São Paulo, Brazil). The cylinders were then sectioned in cutting equipment at 1200 rpm with abundant water cooling (BioPDI Metallographic Cutter, São Carlos, São Paulo, Brazil) to obtain seventy disc-shaped specimens with 12 ± 0.05 mm in diameter and 1.5 ± 0.05 mm in thickness.[10–13] The specimens were subjected to crystallization in a Vita Vacumat 6000MP furnace (Vita Zahnfabrik, Bad Säckingen, Baden-Württemberg, Germany) according to the manufacturer's recommendations.

Finishing was carried out on the flat faces of the specimens on Struers equipment (Sultrade, São Paulo, São Paulo, Brazil) operating at 250 rpm using silicon carbide (SiC) abrasive sandpapers. The disc-shaped specimens were pressed by hand by a single operator on the SiC sandpaper. Finishing was performed in the following order of SiC abrasiveness: #400, #600, #800, #1000, and #1200 Grit for 5 minutes each under intense water cooling. The discs were divided into seven groups (n = 10) according to the surface treatment *(Table 1)*.

Table 1. Groups and surface treatments applied to ZLS specimens.

Groups	Surface Treatment
Control	No treatment; finished by 1200 Grit
FF	Diamond bur 3098 FF; simulating occlusal adjustment without polishing
FFPol	Diamond bur 3098 FF + polishing with Vita Suprinity Polishing Set Clinical kit
FFGl	Diamond bur 3098 FF + application of Vita Akzent Plus Spray glaze
F	Diamond bur 3098 F; simulating occlusal adjustment without polishing
FPol	Diamond bur 3098 F + polishing with Vita Suprinity Polishing Set Clinical kit
FGl	Diamond bur 3098 F + application of Vita Akzent Plus Spray glaze

A single trained operator performed the adjustment with diamond burs 3098F and 3098FF (KG Sorensen, Cotia, SP, Brazil) coupled to a high-speed motor up to 450.000 rpm (Gnatus, Barretos, SP, Brazil) under constant water-cooling. The burs were replaced every three specimens to avoid wear of the burs used. Pilcher *et al*. reported decreased cutting efficiency due to wear after 20 cuts for single-use and multiple-use diamond burs.[14] Jakovljević *et al*. also observed weight loss of diamond burs after 10 minutes of cutting time on glass-ceramic substrates.[15] The bur long axis was placed parallel to the disc surface, covering the entire surface for a pre-determined time of 10 seconds.[16,17]

For the groups FPol and FFPol, the polishing was carried out with the abrasive rubbers of the intraoral polishing kit Vita Suprinity Polishing Set clinical (Vita Zahnfabrik, Bad Säckingen, Baden-Württemberg, Germany). The polishing was carried out in two steps; pre-polishing and high-gloss polishing. The diamond-coated pink tip was used for prep-polishing. Later, the grey diamond-coated tip was used for the high-gloss polishing per the manufacturer's working instructions. Matzinger *et al*. also showed the importance of chairside final high-gloss polishing for glass ceramics to ensure smooth surfaces similar to labside polishing.[18] Each abrasive tip was used without polishing paste for 30 seconds totaling 60 seconds for each sample. The procedures were performed using light hand pressure by only one operator previously trained, using a handpiece that operates at a speed of 10,000 rpm.[19] The FGl and FFGl groups received a layer of Vita Akzent Plus glaze spray (Vita Zahnfabrik, Bad Säckingen, Baden-Württemberg, Germany), sprayed intermittently from a distance of 15 cm. The specimens were taken to the Vita Vacumat 6000 MP furnace (Vita Zahnfabrik, Bad Säckingen, Baden-Württemberg, Germany) and fired using the program recommended by the manufacturer.[5,20]

After all the treatments surface, every specimen was measured to confer the thickness of 1.2 mm ± 0.2 mm as per ISO 6872.[11]

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SURFACE ROUGHNESS

To evaluate the effect of different surface treatments and correlate with the flexural strength, all specimens were thoroughly cleaned with deionized water in an ultrasonic bath for ten minutes,[21] and scanned individually with the profilometer (Hommel-Etamic W10, Villingen-Schwenningen, Baden-Württemberg, Germany). Multiple scans of a smaller region of 1.25 mm were performed to calculate the surface roughness of the entire specimen. The device was calibrated with a measurement filter at 0.25 mm (cut-off), a reading speed of 0.1 mm/s, and an evaluation length of 1.25 mm. Three readings were taken in three different positions parallel to each other, with the discs treated surface facing upwards. The specimens were then rotated by 90°, and three more readings were performed. The mean surface roughness (Ra) was computed from six measurements on each specimen.

BIAXIAL FLEXURE STRENGTH TESTING

The thickness of all specimens was measured before the test to ensure the required dimensions to perform the biaxial flexural test, and each specimen was positioned with the treated surface in tension. A polyester strip was used between the specimen and the loading piston to distribute the contact pressure evenly.[11,22] The biaxial flexural test was performed on a universal testing machine (EMIC DL 10000/700 - São José dos Pinhais, Paraná, Brazil) with a speed of 0.5 mm/min, registering the force required to fracture the specimen.

The biaxial flexural strength was calculated using the following equations, as described in ISO 6872.[11]

$$\sigma_{\max} = -0.2387\,P\,\frac{(X-Y)}{t^2}$$

$$X = (1+\nu)ln(b/R)^2 + [(1-\nu)/2]\,(b/R)^2$$

$$Y = (1+\nu)[1+ln(a/R)^2] + (1-\nu)\,(a/R)^2$$

where:

σ_{max} = maximum stress (in MPa)

P = fracture load (in N)

t = disc thickness (in mm)

R = radius of the disc (in mm)

a = radius of the support circle (5 mm)

b = radius of the loading ball (0.8 mm)

v = Poisson's ratio (0.25)

X = Function of b/R

Y = Function of a/R

OPTICAL AND ATOMIC FORCE MICROSCOPY

The fractured specimens were cleaned in an ultrasonic bath (Model 150T, Aqua Sonic, VWR scientific products, Radnor, Pennsylvania, USA) for 5 minutes using enzymatic detergent (Multi-Purpose Enzyme Tablets, Patterson Dental Supply, Saint Paul, Minnesota, USA). They were then washed with distilled water to remove the detergent and dried with compressed air. The fracture surface of the specimens was placed on a microscope slide facing up with modeling clay (Sculpey III, Polyform Products Company, Elk Grove Village, Illinois, USA) and was taken to an optical microscope (VHX-1000, Keyence, Itasca, Illinois, USA) to verify the failure origin.

Then, three specimens from each group were taken to the atomic force microscope (AFM, Bioscope Catalyst, Bruker, Santa Barbara, California, USA) to analyze the surface topography of the disc. An area of 50 μm x 50 μm near the fracture origin was scanned using the "Peak Force Tapping mode" with a resolution of 512 x 512 pixels, a scan rate of 0.977 Hz, using a Scan-Asyst Air probe. A 3D image of the surface was generated in the Gwyddion software - Version 2.47 (Czech Metrology Institute, Brno, Czech Republic).

FRACTOGRAPHY

Fractured specimens were cleaned using an ultrasonic bath with isopropyl alcohol for 5 minutes. Firstly, all the specimens were observed using a stereomicroscope (Discovery V20, Carl Zeiss, Jena, Thuringia, Germany) to identify the fracture features present on the fracture surface. Then, representative specimens from each group were analyzed using scanning electron microscopy (SEM) (Magellan 400L, FEI Company, Brno – Moravia, Czech Republic).

STATISTICAL ANALYSIS

The Shapiro-Wilk and Bartlett tests were performed to verify the normality of the residuals and equality of the variances, respectively. The roughness data were analyzed using a one-way ANOVA and post-hoc Tukey's test, and the flexural strength data were analyzed by the Kruskal-Wallis test with Dunn's post-hoc test. All the statistical analyses were performed using the R software, and the significance level was set at 5%.

RESULTS

The surface roughness varied significantly between different surface treatments ($p < 0.001$) (*Table 2*). Higher surface roughness was observed for groups roughened with diamond bur F, with or without glaze application. When using the FF bur, roughness values similar to the FGl and FFGl groups were observed. After polishing, similar roughness values (Ra) were observed, regardless of the type of bur used.

The control and the glazed treated specimens had a higher mean flexural strength than the polished ones ($p < 0.001$). There was no significant difference between control, FGl, and FFGl groups. The F, FF, FPol, and FFPol groups had statistically similar flexural strength *(Table 2)*.

Table 2. Biaxial flexural strength and surface roughness for different surface treatments: mean and standard deviation (SD).

Groups	Flexural Strength (MPa)		Surface Roughness (µm)	
	Mean	SD	Mean	SD
Control	207.84[a]	70.63	0.025[e]	0.010
FF	119.45[b]	21.98	1.211[bc]	0.209
FFPol	114.36[b]	20.96	0.894[d]	0.152
FFGl	227.62[a]	71.88	1.124[bcd]	0.302
F	109.23[b]	15.98	1.693[a]	0.165
FPol	127.51[b]	19.80	1.149[cd]	0.131
FGl	206.97[a]	27.18	1.385[ab]	0.413

* Different smaller case letters within the same column indicate statistical difference between the different groups.

The atomic force microscope images depict the surface topography *(Figure 1)*, and the graphs show the roughness profile *(Figure 2)*. The z range between the peak and valleys in groups that were not polished or glazed is larger than the other groups.

SEM micrographs show the fracture markings n every specimen *(Figure 3)*. The compression curl assisted in locating the fracture origin (solid white arrow). The crack originated in the tensile region in all specimens, where the surface treatment was performed and propagated towards the compressive side.

The representative fractured surfaces show the defects of FFGL and FF, which, judging by their similarities, were caused by bur.

DISCUSSION

Although contraindicated, the occlusal or interproximal surfaces of ceramic prosthetic restorations are usually adjusted. The adjustment is typically performed with F (45-50 µm) or FF (15-30 µm) diamond burs.[23] It can sometimes break the uniform and smooth superficial layer created during the firing of the ceramics. In addition to increasing the roughness, it can also result in clinical problems such as wearing of the antagonist tooth, plaque retention, tissue inflammation, and alteration of esthetics, besides decreasing the strength. Therefore, it is necessary to perform polishing in the adjusted areas.[3,16]

Surface roughness is defined as a set of irregularities in the form of small projections and recesses that lead to stress concentration.[24] These concentration points can promote a vast system of micro-cracks instead of a single precisely defined fracture.[25] These stress concentrations will result in lower strength[26,27] as seen in the groups adjusted with diamond burs in this study. The hypothesis that the type of diamond bur (F or FF) used for adjustment does not influence flexural strength was accepted. The flexural strength values were similar between the groups with different types of diamond burs.

After these adjustments, there is a need to regularize the surface to eliminate the surface roughness to obtain acceptable smoothness and shine, and can be performed with the polishing rubbers or by applying the glaze.[16,23] The initial hypothesis that surfaces with lower roughness would have a greater flexural strength was accepted only for the control group. The groups where the polishing was applied showed a lower surface roughness than the groups with the application of glaze and wear groups; this result seems favorable for polishing when considering the isolated roughness factor. However, the polished groups showed biaxial flexural strength similar to the group in which only the adjustment with burs was performed.

In the groups where the glaze was applied, the strength values were higher than those that received polishing after wearing with burs but similar to the control group without wear even though they had a higher surface roughness.

The surface roughness (Ra) was recorded in this study, Ra refers to the absolute distances of the roughness profile at the intermediate height and the measured length.[28] The main factor for reduced strength is the shape of the defect, regardless of the peak height.[29] Rounded defects result in small radial cracks, whereas sharp defects cause wedge-shaped micro-cracks, accumulating stresses that cause the material to fracture,[30] and therefore are more critical. Thus, polishing may only have smoothened out the superficial layer without correcting the inner defects, and the glaze may have filled the flaws, thus preventing stress concentration points.[31] It is also observed with the surface topography analysis using the AFM, where the specimens in polishing groups have smaller features. The z-range is also smaller than the groups subjected to only wear. The specimens treated with glaze have a higher z-range than the polishing group showing that glaze doesn't smoothen out the surface.

The fracture surface analysis is used to identify the fracture origin and characterize specific aspects of the failure.[32] The failure origin is usually located on the tensile side, where the stress concentration is highest. The crack then propagates to the compressive side, giving rise to the compression curl region.[33] The results obtained in the flexural and roughness experiments are evidenced in the fractographic analysis, where the tensile region have critical defects and microcracks caused by the diamond burs (F or FF). Zipper cracks are observed in the critical defect region

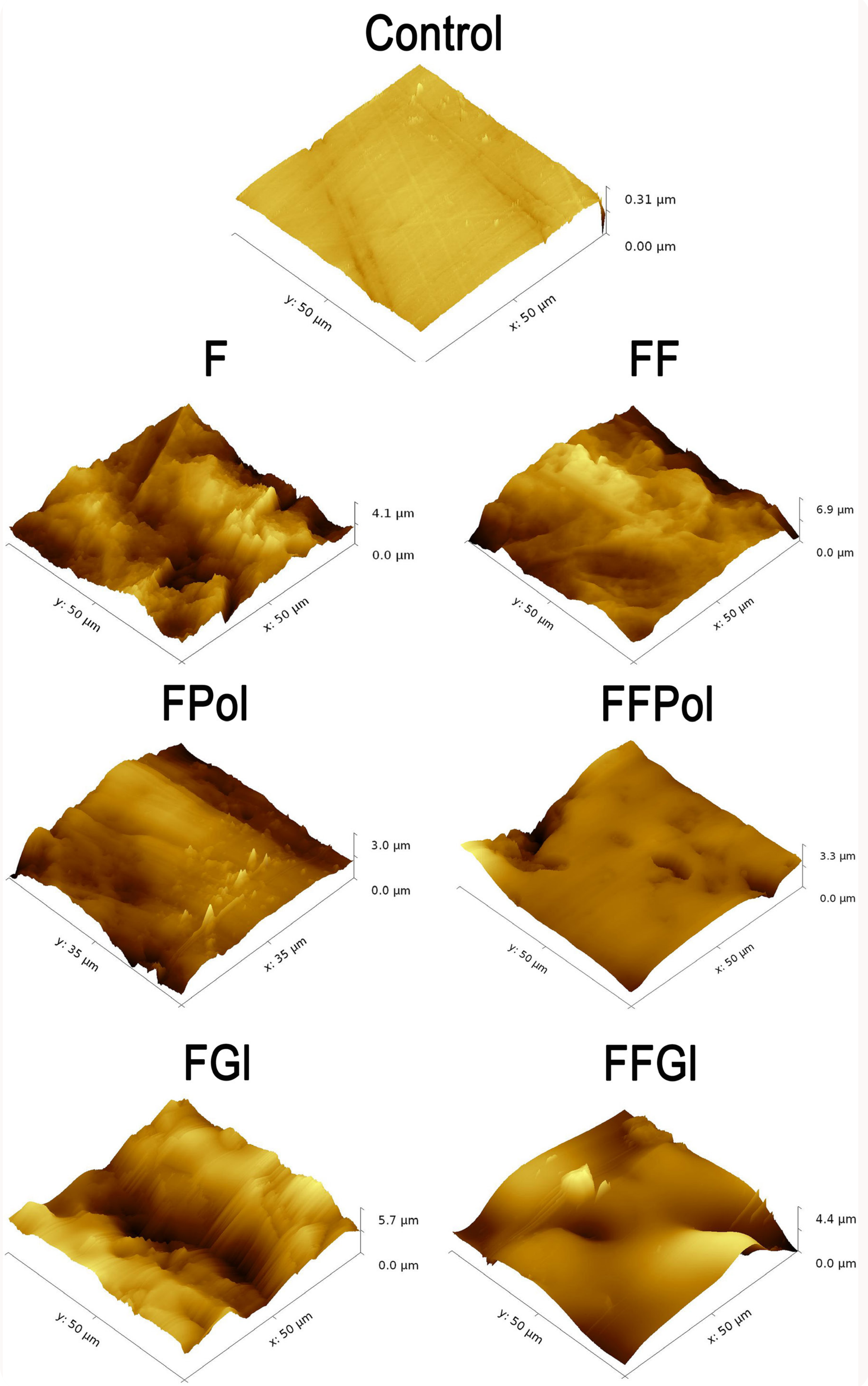

Figure 1: 3D topography of the surface from AFM scans of a representative specimen from each group.

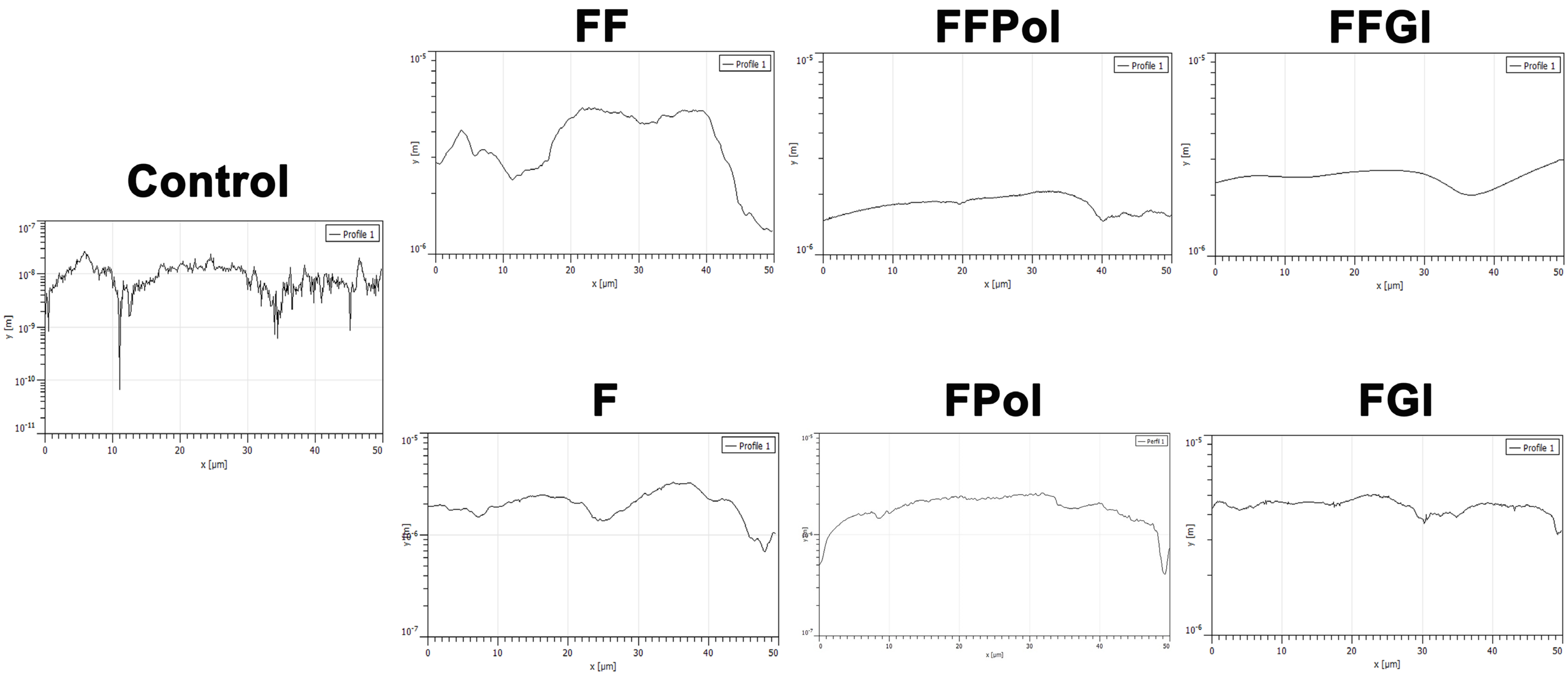

Figure 2: Surface roughness profile of a representative specimen from each group using the AFM.

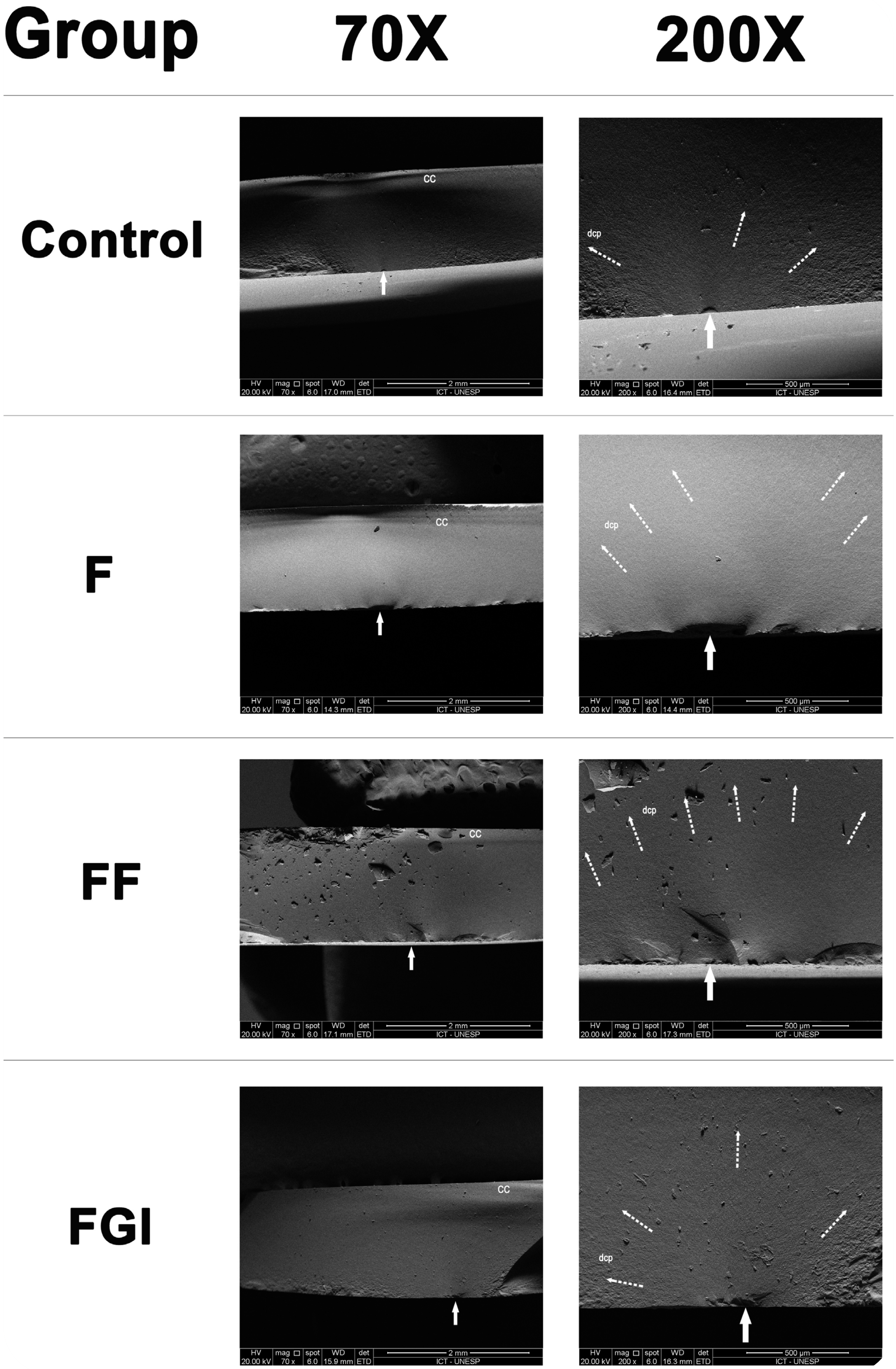

Figure 3: SEM micrographs (left at 70x, and right at 200x) of a representative specimen from each group. Solid white arrow points at the fracture origin. Dotted white arrows show the direction of crack propagation (dcp). White asterisks indicate damage to the surface. CC: compression curl.

showing the effect of rolling the bur on the ceramic surface.[34] The specimens in FPol and FFPol have lesser surface defects as compared to F, or FF treated ones. In groups FGl and FFGl, these defects are smaller due to the infiltration of glaze.

It is assumed that some defects were caused before the surface treatment, such as the crystallization process, which may give rise to defects that can lead to fracture due to the composition of the Suprinity ceramic, which results in a material with a microstructure resistant to polishing.[34]

In this study, the application of glaze was evaluated under non-aged conditions, however, chipping or delamination of the surface could clinically occur due to the application of masticatory conditions, temperature and contact with salivary fluids.[35] Thus, other studies should be conducted in order to assess the longevity of the application of glaze.

The Vita Suprinity Polishing Set Clinical polishing kit does not use polishing paste, and according to some studies,[28,36,37] this may not make the surface adequately smooth, as the polishing paste contributes to a smoother surface when compared to glaze. Al-Wahadni[3] and Martin *et al*.[30], indicated the use of the polishing Kit with polishing paste, because the small diamond-paste particles would thus be expected to produce smoother surfaces that would be less abrasive, being capable of producing a smooth surface similar to glaze or better. Other studies consider a combination of glaze, polishing, and polishing paste as even more effective than just polishing or glaze separately.[28,38]

Therefore, further studies are needed to assess whether other types of polishing would smoothen the defects caused by the diamond burs. Clinically it can be considered that a polished and glazed surface is more favorable because the glaze will wear out after some time, exposing the adjacent surface, which if polished will be less harmful to the antagonist and will accumulate less biofilm.

According to the study it can be concluded that:

- The use of diamond burs increases surface roughness and decreases the biaxial flexural strength of ZLS ceramic, regardless of the granulation of the bur used (F or FF). -The polishing results in a smoother surface but decreases the flexural strength.
- The use of glaze increases the flexural strength of ZLS ceramic after adjustments with diamond burs, disregarding the influence of aging on the clinical longevity of the glaze.

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CONFLICTS OF INTEREST

There are no conflicts of interest.

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