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Characterization of Reinforced and Unreinforced Glass-Ceramic Veneers

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Clinical Relevance

Ceramic veneers fabricated using CAD/CAM technology require careful inspection by the dentist before cementation to assess surface smoothness and integrity, as those can affect the esthetics and lifetime of the restoration. Polishing is an effective technique to reduce the surface roughness of zirconia-reinforced lithium silicate and feldspathic ceramics. The presence of residual stress in these ceramics also plays an essential role in predicting their performance over time, as high residual stresses have a negative effect.

SUMMARY

This study aimed to characterize the surface topography, effect of polishing on surface roughness, residual stresses, and hardness in two glass-ceramic veneers. Fifty-two (52) upper incisors were collected, prepared, and scanned for ceramic veneers. Half of the teeth were restored with veneers made up of feldspathic ceramic (FE), and the other half with zirconia-reinforced lithium silicate ceramic (SZ). All the veneers were designed and milled using a CAD/CAM system and later cemented following the manufacturer's guideline. An optical microscope analyzed the topography of the specimens before and after polishing. The surface roughness was measured using the roughness meter (n=12) and the topographical analysis was carried out using an atomic force microscope (n=6). The residual stresses and Vickers' hardness were evaluated by the indentation method in a micro-hardness indenter (n=6). The surface roughness was analyzed using a three-way analysis of variance (ANOVA) followed by a *post hoc* Tukey test. The Student *t*-test was used to compare the residual stresses and hardness between the two ceramics. The topographical analysis revealed that both glass-ceramic veneers had similar percentages of specimens with cracks, before (34.6%) and after (42.3%) polishing. The surface roughness decreased after polishing (p<0.001),

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and the polishing smoothed out the surface of the veneers. The zirconia-reinforced lithium silicate veneer had a lower roughness as compared to the feldspathic one after polishing, while the residual stresses (*p*=0.722) and hardness (*p*=0.782) were statistically similar for both ceramic veneers.

INTRODUCTION

Veneering restorations made of ceramics exhibit chemical stability, biocompatibility, high compressive strength, color stability, and a smooth surface, along with a close appearance to the natural tooth.[1] Ceramic veneers as thin as 0.3 to 0.5 mm have been reported to be clinically successful.[2]

The feldspathic ceramic (FE) is composed of an amorphous glassy matrix and an irregularly shaped crystalline phase, where leucite stands out (17% to 25%). Although this type of ceramic has excellent optical properties, the large amount of amorphous matrix needed results in lower mechanical properties than glass-ceramics with higher crystalline content.[3] The increase of crystalline content within the glass matrix in the microstructure of ceramics yields a significant increase in their mechanical properties. A new ceramic was conceived when zirconium dioxide (approximately 10% by weight) was added to lithium silicate glass, zirconia-reinforced lithium silicate (SZ) ceramic, commercially available as Vita Suprinity (Vita Zahnfabrik, Bad Säckingen, Germany). The zirconia fillers act against crack propagation and provide higher fracture resistance and flexural strength to the ceramic material.[4,5]

These dental ceramics are available in blocks that can be processed by computer-aided design and computer-aided manufacturing (CAD/CAM) technology.[6,7] These blocks exhibit a more homogeneous composition with fewer internal defects.[8,9] However, the literature claims that the abrasive diamond burs used for the milling process can incorporate superficial defects or cracks in the ceramic,[10,11] and also can roughen the surface that will later require polishing.[12] On rough surfaces, there is a higher risk of biofilm accumulation and development of cracks, in addition to being abrasive and causing more considerable wear of the antagonist.[13] A smooth ceramic surface is important for patient comfort, esthetics, and biological aspects. Therefore, the finishing and polishing of ceramics are essential steps and can be accomplished using abrasive rubber tips or by the application of glaze, or even by a combination of these two techniques.[14]

This study aims to characterize the surface topography, effect of polishing on surface roughness, residual stresses, and hardness of FE and SZ ceramic veneers. The following hypotheses were tested: 1) the topographic evaluation will identify the presence of surface defects; 2) the polishing will decrease the surface roughness of ceramic veneers; and 3) FE and SZ ceramic veneers will have similar residual stresses and hardness after milling.

METHODS AND MATERIALS

Specimen Preparation

Fifty-two (52) human upper central incisors were collected following ethics committee approval. The teeth were cleaned following the protocol proposed by the tooth bank of the University of Western São Paulo - UNOESTE and stored in deionized water for a maximum of six months.

The teeth were divided into two experimental groups (n=26), according to the ceramic materials used to fabricate the veneering restoration, as follows: Group FE - feldspathic ceramic (Vita Mark II, Vita Zahnfabrik); Group SZ - zirconia-reinforced lithium silicate ceramic (Vita Suprinity, Vita Zahnfabrik). For randomization, Research Randomizer software (Version 4.0, https://www.randomizer.org) was used, defining the distribution of the specimens.

Before preparation of the teeth, a silicone mold (Scan Putty, Yller Biomaterials SA, Pelotas, Brazil) of each tooth was taken and used as a guide to control thickness (0.5 mm).

The teeth were prepared by a single trained operator, with diamond burs 4138 F and 4138 FF (KG Sorensen, Barueri, SP, Brazil), following the dimensions and shapes of the conventional preparation for ceramic veneers,[15] preserving the proximal contacts and covering the incisal edge without creating a palatal chamfer. Each set of burs was used to make three preparations.

All teeth were scanned with the InEos Blue optical scanner system (Cerec - Sirona Dental Systems, Bensheim, Germany). The veneer design was standardized to 11 mm height and 0.5-mm thickness using the InLab SW4 software (Cerec - Sirona Dental Systems). The prototypes were transferred to the InLab MC XL milling machine (Cerec - Sirona Dental Systems) to mill 26 veneers in SZ and the other 26 veneers in FE.

The crystallization cycle for SZ was performed in the Vita Vacumat 6000MP (Vita Zahnfabrik) furnace according to the manufacturer's recommendation. All laminates received a layer of VITA AKZENT Plus glaze spray (Vita Zahnfabrik), and were taken to the Vita Vacumat 6000 MP furnace (Vita Zahnfabrik) for firing using the program recommended by the manufacturer.

For cementation, each tooth was conditioned with 37% phosphoric acid (Cond AC 37%, FGM, Joinvile, SC, Brazil) for 30 seconds, rinsed (30 seconds), and dried (20 seconds). Then, two layers of the universal adhesive system (Single Bond Universal, 3M Oral Care, St Paul, MN, USA) were applied for five seconds on the surfaces, followed by drying using an air jet for five seconds at a distance of 15 cm. The adhesive was not light-cured.[16,17]

The cementation surface of both the FE and SZ veneers was etched with 10% hydrofluoric acid (HF, Cond AC Porcelana, FGM) for 60 seconds and 20 seconds, respectively, rinsed (30 seconds), and dried (30 seconds). The ceramic veneers were cleaned in an ultrasonic bath with deionized water for 1 minute and dried. A silane bonding agent (RelyX Ceramic Primer, 3M Oral Care) was applied and allowed to react for one minute.

The veneers were cemented onto the corresponding teeth using the resin cement RelyX Veneer (3M Oral Care). Initial light-curing (3 seconds) was performed to remove the excess resin cement followed by light curing (Bluephase N, Ivoclar Vivadent, Schaan, Liechtenstein) of the buccal, incisal, and lingual free surfaces of the tooth for 20 seconds at a light intensity of 1.2 mW/cm^2. The restored teeth were then stored in deionized water for two weeks.

Inspection and Determination of Veneer Surface Roughness

All specimens were observed under an optical microscope (VHX-1000, Keyence, Itasca, IL, USA) to check for cracks and irregularities. Any cracks found were recorded for later comparison.

A replica of each specimen was created for analyzing the surface roughness and topography.[18,19] The replicas of the three thirds (cervical, middle, and incisal) of each veneer were used instead of the real samples to easily accommodate them under the analytical instruments. For this, a mold was prepared using a polyvinylsiloxane impression material (Extrude, Kerr Corporation, Orange, CA, USA) and filled out with epoxy resin (EpoxySet, Allied High Tech Products Inc, Rancho Dominguez, CA, USA). After the epoxy hardened, the replicas were removed from the mold and analyzed using the optical microscope to ensure that they were free of bubbles and artifacts.

The surface roughness was determined using a roughnessmeter (Hommel-Etamic W10, Schwenningen, Germany) on 12 replicas with no cracks from each group. The device was calibrated with a measurement filter of 0.25 mm (cut-off), 0.1 mm/s (speed), and a reading length of 1.25 mm. The surface roughness in three regions (cervical, middle, and incisal) of the epoxy replica of the ceramic veneer was measured. The same replicas were used for topographical analysis using the atomic force microscope (AFM, Bioscope Catalyst, Bruker, Santa Barbara, CA, USA).

The topographical analysis of those three regions was performed using an AFM (Bioscope Catalyst) on six replicas of each group. The AFM has a limitation in the z range that does not allow placing a sample higher than 3 mm under the probe, which is why a replica of the specific region of interest was used. Studies have shown that there is no difference between the data obtained from a replica and the actual sample.[18,19] The AFM was used in Peak Force Tapping mode with a Scan-Asyst Air probe (Bruker, Santa Barbara, CA, USA), at a resolution of 512 x 512 pixels. A single region of 50 μm x 50 μm was scanned at a scan rate of 1 Hz. The scanning rate was optimized to the highest value such that the trace and retrace height curve were tracking each other. After leveling, a 3D image of the surface was generated using the Gwyddion software - Version 2.47 (Czech Metrology Institute, Brno, Czech Republic).

Polishing

The specimens were then manually polished with the Vita Suprinity Polishing Set clinical kit (Vita Zahnfabrik). The rubber polishing tips were used in decreasing abrasive order. The preliminary polishing was carried out using the pink diamond rubbers, followed by the gray tips for the high gloss polishing. Each tip was used for 30 seconds, totaling 60 seconds,[20] and the procedures were performed using light hand pressure by only one operator (previously trained) using a handpiece that operated at a speed of 20,000 rpm. After polishing, all specimens were inspected and the surface roughness was calculated as mentioned above.

Residual Stresses and Vickers Hardness

Residual stresses were calculated using the microhardness indenter (Clark CM - 400AT, - SunTec Corporation, Novi, MI, USA). After polishing, 12 specimens from each group were selected, six with cracks (found during the inspection with an optical microscope) and the other six without cracks. The buccal surface of the ceramic veneer was indented using a Vickers' diamond with a load of 0.3 kgf for 5 seconds. For the specimens with cracks, the indentations were performed 50 μm away from the crack.

The length of the diagonals of the indentation was measured, and the residual stresses were calculated using equation 1[21, 22]:

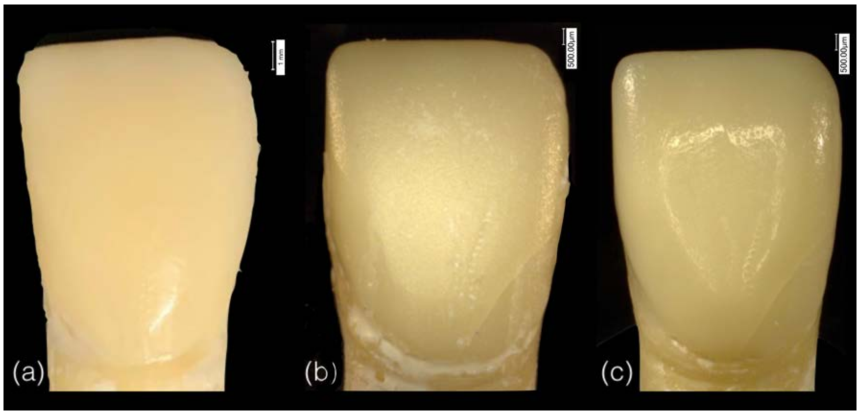

Figure 1. *Suprinity ceramic veneers observed using (A) a digital camera before polishing; (B) an optical microscope before polishing; and (C) an optical microscope after polishing.*

$$\sigma_R = K_{Ic}\left[\frac{1-\left({}^{c_0}/_{c_1}\right)^{3/2}}{\psi c_1^{\,1/2}}\right], \qquad (1)$$

where K_{Ic} is the fracture toughness, c_0 and c_1 are the indentation crack lengths in unstressed (uncracked) and stressed (cracked) materials, respectively, and ψ is a crack geometry factor ($\psi = 1.24$).

The hardness of the ceramics was calculated using equation 2:

$$HV = 1.8544\left(\frac{F}{d^2}\right), \qquad (2)$$

where HV is the Vickers' hardness (kgf/mm^2), F is the indentation force (kgf), and d is the mean diagonal of the indentation (mm).

Statistical Analysis

The normal distribution was tested using the Shapiro-Wilk test. The surface roughness was analyzed using a three-way analysis of variance (ANOVA), and a *post hoc* Tukey test was performed to determine the differences between the groups. The Student *t*-test was used to determine significant differences between FE and SZ ceramic veneers in terms of residual stresses and hardness. A significance level of 5% was used for all the statistical tests.

RESULTS

Inspection of Veneers Before and After Polishing

No cracks or irregularities were observed in the specimens during visual inspection (Figure 1A). However, cracks were observed in 34.6% of the specimens in each group under the optical microscope (Figure 1B, C). Detailed information on the cracks is shown in Table 1.

After polishing, the percentage of specimens with cracks in each group increased to 42.3%. Polishing increased the number of cracks for each material by 7.7% (Table 2).

In most of the specimens, more than one crack was observed (Figure 2A). Initially, excess cement was

Table 1: *Specimens with Cracks Discovered Pre-polishing (Number and Percentage)*

Material	Region					
	Buccal Face N (%)			Lingual Face n (%)	Distal/Mesial Face n (%)	Total n (%)
	Cervical	Middle	Incisal	Incisal	Cervical	
FE	4 (15.3)	4 (15.3)	1 (3.8)	0	0	9 (34.6)
SZ	4 (15.3)	2 (7.6)	1 (3.8)	1 (3.8)	1 (3.8)	9 (34.6)

Abbreviations: FE, feldspathic ceramic; SZ, zironia-reinforced lilthium silicate ceramic.

Table 2: *Specimens with Cracks Discovered Post-polishing (Number and Percentage)*

Material	Region					Total n (%)
	Buccal Face n (%)			Lingual Face n (%)	Distal/Mesial Face n (%)	
	Cervical	Middle	Incisal	Incisal	Cervical	
FE	4 (15.3)	4 (15.3)	2 (7.6)	0	1 (3.8)	11 (42.3)
SZ	6 (23.0)	2 (7.6)	1 (3.8)	1 (3.8)	1 (3.8)	11 (42.3)

Abbreviations: FE, feldspathic ceramic; SZ, zirconia-reinforced lithium silicate ceramic.

observed in the margins of the veneers, but it was removed during polishing (Figure 2B, C).

Surface Roughness

The surface roughness (Ra) of the specimens was reduced significantly after polishing (p < 0.001). There were no differences in roughness between the cervical, middle, or incisal regions of the restoration. As shown in Table 3, the SZ ceramic showed lower Ra after polishing compared to FE (p=0.011).

For both ceramics, the AFM analysis showed sharp asperities and a significant increase in the surface roughness of un-polished specimens as compared to the ones that were polished, regardless of the region that was scanned (Figures 3 and 4).

Residual Stresses and Vickers Hardness

There was no significant difference in residual stresses (p=0.782), and hardness (p=0.722) between the two ceramics (Table 4).

DISCUSSION

Cracks were observed in both of the ceramic materials after using an optical microscope. The milling process may have resulted in the formation of these cracks. Some of the energy involved in the milling process is released in the form of heat, resulting in an increase in temperature at the cutting site. This high temperature and the cooling generated by irrigation create a thermal exchange that may contribute to the generation of residual stresses and cause surface damage.[10,11,13,14]

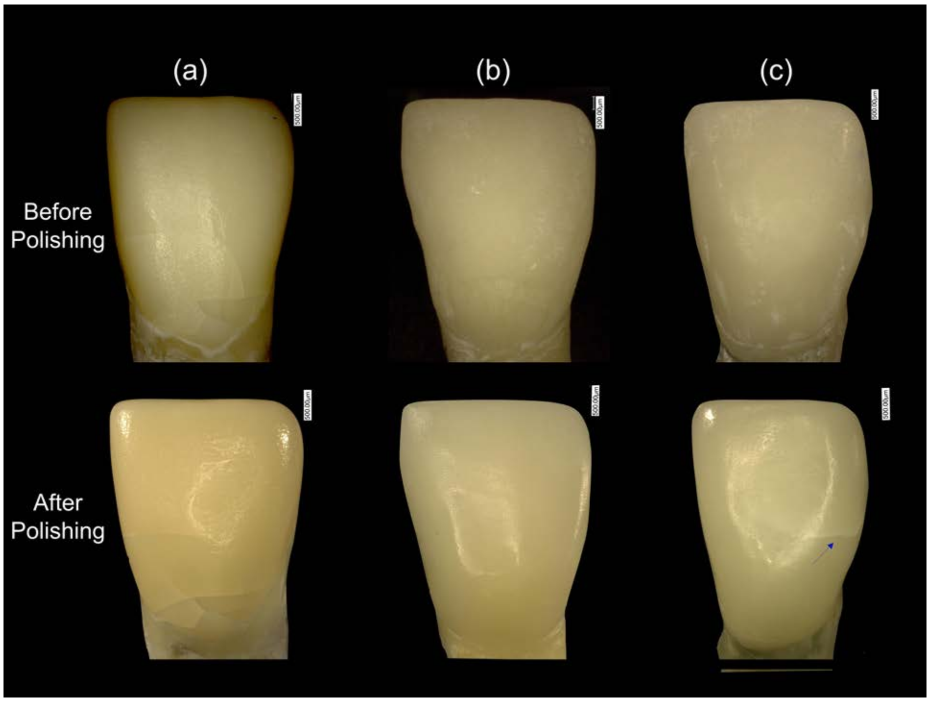

Figure 2. *Buccal aspect of the specimens, before (top figures) and after polishing (bottom figures). (A) Multiple cracks in the cervical region; (B) Excess cement observed in the margins before polishing; (C) New cracks observed after polishing (blue arrow).*

Table 3: *Surface Roughness (µm) of FE and SZ Ceramic Veneers Before and After Polishing*[a]		
Polishing	**Ceramic**	
	FE	**SZ**
Before	1.33 ± 0.01 Aa	1.23 ± 0.01 Aa
After	0.56 ± 0.01 Ba	0.38 ± 0.01 Bb

Abbreviations: FE, feldspathic ceramic; SZ, zirconia-reinforced lithium silicate ceramic.
[a]*Different upper case letters in the same column indicate statistical difference within the same column, and different lower case letters in the same row indicate statistical difference among different ceramics.*

These cracks are difficult to visualize and can be missed by the dentist. Indeed, the cracks found on the specimens were not noticeable with visual inspection and could only be seen under an optical microscope on a 500-µm scale, using transillumination. Such surface damage could have been observed with the use of medium or high magnification dental microscopes (8x to 30x)[23]; however, they are not commonly used in most dental offices due to their high cost.[24] A handy option to visualize the cracks would be the use of dental loupes that, according to their classification in Galilean and Keplerian loupes (prismatic), have a magnification ranging from 2.5x to 6x.[25] The use of white light for transillumination is also recommended for this inspection since cracks and subsurface flaws redirect the light and form a dark shadow, making them more evident to the naked eye.[26]

In the present study, the location of several cracks seemed to be related to the location of the sprue on

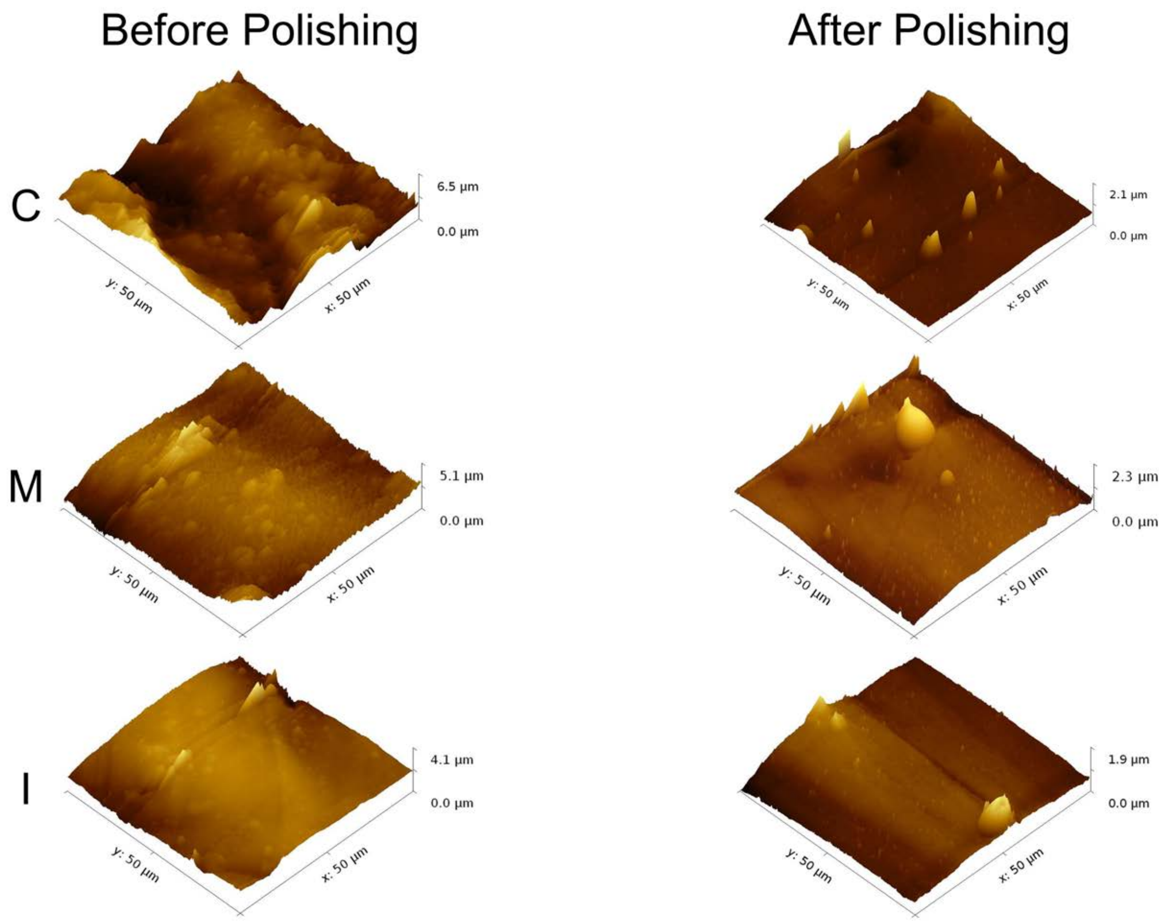

Figure 3. *A 3D image of feldspathic ceramic before and after polishing. The letters indicate the regions that were scanned, where C: cervical; M: middle; and I: incisal.*

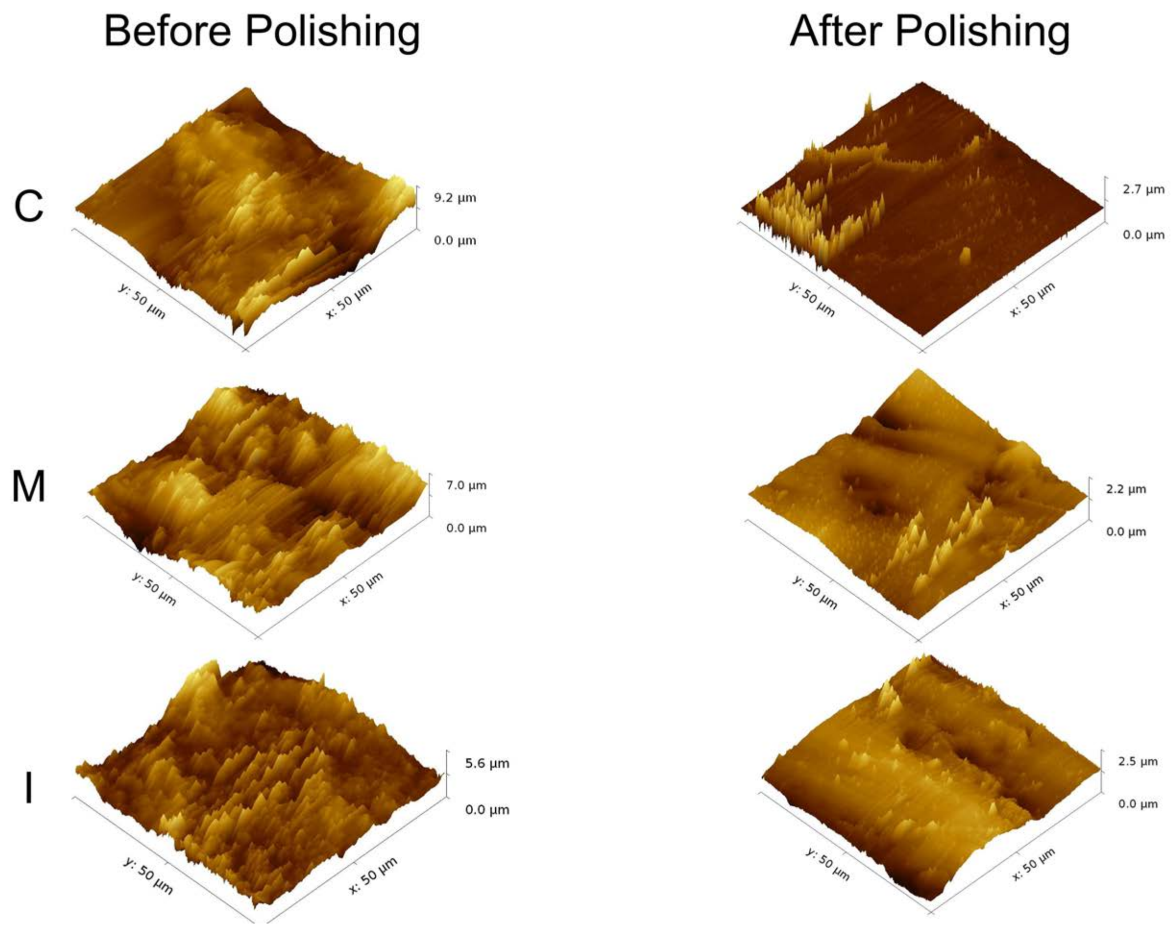

Figure 4. *A 3D image of the zirconia-reinforces lithium silicate ceramic before and after polishing. The letters indicate the regions that were scanned, where C: cervical; M: middle; and I: incisal.*

the veneer surface left after the milling process. The hypothesis that the topographic evaluation will identify the presence of surface defects was accepted.

The diamond burs used during the milling can result in rougher surfaces that may require finishing and polishing. In the pre-polishing analysis, a rough surface was seen on both of the ceramics, as also observed by Mota and others,[12] who reported a higher Ra value before polishing in all the evaluated ceramics. The hypothesis that the polishing would reduce the roughness of ceramics was accepted because all specimens showed lower Ra after polishing. The SZ ceramics had a lower roughness compared to FE when polished. This may be due to the smaller crystal size and higher zirconium dioxide content of the SZ ceramic.[27] The polishing set used may have caused more considerable wear and tear on the vitreous structure of the FE ceramic, generating a more irregular surface compared to SZ.

The Vickers' indentation method can be used to estimate residual stresses and hardness in brittle materials.[21,22]

Table 4: *Mean and Standard Deviation (SD) of Residual Stresses and Vickers' Hardness*[a]

Group	**Residual Stresses**		**Vickers' Hardness (kgf/mm^2)**	
	Mean	**SD**	**Mean**	**SD**
FE	25.49 a	7.98	670.26 A	47.16
SZ	23.31 a	17.03	649.89 A	128.13

Abbreviations: FE, feldspathic ceramic; SZ, zirconia-reinforced lithium silicate ceramic
[a]*The same case letters within the same column indicate no statistical difference between the FE or SZ groups.*

For ceramic materials without residual stresses, a well-defined symmetrical indentation and cracks of similar lengths (c_0) emanating from the four corners of the indent without crack branching are observed.[21,22] However, in specimens with cracks, residual stresses contributed to the formation of radial cracks after indentation.[21] The FE and SZ ceramics showed similar values of residual stresses. In SZ, the pre-existing cracks may have promoted a transformation zone of the zirconia crystals[28]; however, the volume fraction of transformation may have been non-uniform within the zone, leading to the development and propagation of new cracks[29] and the extrusion of grains.[28] This may have caused degradation of the material strength to a level comparable to that of FE ceramics. For residual stresses, the hypothesis of similarity between FE and SZ ceramics was accepted.

Surface hardness is defined as the material's ability to resist indentation and is generally associated with the material's stiffness. It was expected that both materials, FE and SZ, would show similar hardness values since both of them belong to the glass-ceramics family and were produced and polished using the same protocol. In 2015 Lebon and others[30] reported that the greater the hardness of the ceramic, the greater the surface roughness. The average hardness values for FE obtained by Sen and Us[3] in 2018 (658.69±69 kgf/mm^2) were close to those found in the present study (670.26±47.1 kgf/mm^2). For SZ, the result obtained in this study (649.89±128.13 kgf/mm^2) is similar to the one determined by Elsaka and Elnaghy[4] in 2016 (665.8±46.9 kgf/mm^2) and reported by the manufacturer (713.8 kgf/mm^2). Hardness measurement provides information about the abrasiveness of materials when they interact with natural dentition, which is important when choosing dental materials.

This study was limited by the presence of cracks in the specimens, which decreased the sample size for some of the tests but warned of the need for a careful inspection of the veneers. These cracks may have been introduced by milling or cementation since inspection under an optical microscope was carried out after the veneers were cemented. In this regard, future studies should be conducted in order to identify other potential factors responsible for the formation of cracks observed in both the materials, as well as to determine the influence of the cracks on the ultimate strength of the veneer-tooth set.

CONCLUSION

Subsurface cracks were observed in both glass-ceramic veneers made of feldspathic and zirconia-reinforced lithium silicate ceramics. The polishing decreased the surface roughness of the veneers. Zirconia-reinforced lithium silicate veneers had the lowest roughness after polishing. The residual stresses and hardness values were similar between the two ceramics studied.

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Regulatory Statement

This study was conducted in accordance with all provisions of the human subjects oversight committee guidelines and policies of the Unoeste Research Ethics Committee. The approval code issued for this study is CAAE number 79435217.1.0000.5515.

Conflict of Interest

The authors declare that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company mentioned in this article.

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