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EVALUATION OF POLISHING EFFICIENCY IN DIFFERENT REGIONS OF LITHIUM DISILICATE OVERLAYS THROUGH PROFILOMETRY SIMULATING CLINICAL CONDITIONS

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ABSTRACT

This in vitro study evaluated the efficiency of polishing maneuvers on different areas of milled lithium disilicate overlays using contact profilometry, simulating clinical conditions. Six milled lithium disilicate overlays were fabricated using a computer-aided design (CAD) and computer-aided manufacturing (CAM) system. For each sample, three specific regions were selected: an external smooth slope (ES), an internal grinding slope (IS), and a proximal area between the marginal ridge and the proximal fossa (FO), and three different conditions were tested, namely: glazing, finishing, and polishing. The finishing system was composed of fine and ultrafine diamond points, and the polishing system used was rubber points. Contact profilometry enables the generation of a quantitative assessment through roughness profiles and a qualitative evaluation through three-dimensional (3D) images. The overlays' average surface roughness (Ra) was assessed using a profilometer, 3D images were obtained using the Talymap software, and Ra data were compared using one-way analyses of variance ($p<0.05$). The results revealed that there were statistically significant differences between the dental area ($p=0.049$), surface treatment ($p<0.00$), and the interaction between the factors ($p<0.00$). Considering the treatment factor, statistically significant higher roughness was found in the polished FO group ($p<0.05$). The fossa is a non-flat region with high masticatory demand; its statistically significantly higher roughness for polishing allows us to assume that access to polishing instruments is limited in this region, preventing efficient action. Such finishing and polishing procedures are widely used

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in clinical practice and demand our attention regarding their effectiveness in the different areas of ceramic restoration.

Keywords: Lithium disilicate. Polishing. Surface roughness.

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INTRODUCTION

Advances in computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies, along with the development of high-strength dental ceramics, have led to monolithic restorations. These restorations respond to the challenges faced by double-layer restorations, which often result in chipping (Lawson et al., 2014; Alao et al., 2017; Kurt et al., 2019).

As an excellent treatment alternative that allows the tooth's structure to be mimicked, ceramics made from lithium disilicate (LD) are predominantly used in dentistry due to their aesthetic properties and high resistance to flexion (Sasany et al., 2022). LD ceramics, such as IPS and e.max CAD (Ivoclar Vivadent, Liechtenstein), can be processed by CAD/CAM milling to ensure accuracy and reduce intrinsic defects (Alao et al., 2017). However, milling can introduce surface and subsurface defects, affecting strength compared to traditional pressing techniques (Fraga et al., 2015; Alao et al., 2017; Pilecco et al., 2022). In this context, after milling, it is necessary to apply a fluid layer of low-fusion ceramic to the surface of the restoration, applying the glaze. This step promotes sealing surface defects, generating smoothness and shine on the ceramic surface (Kurt et al.,2019). Another option would be to mechanically polish the surfaces with sequences of instruments and polishing pastes.

When installed, LD restorations are often adjusted with fine-grained diamond points that partially remove the superficial glaze layer, resulting in rougher surfaces with changes in surface topography, color, and shine, especially in areas of chewing load and deep grooves (Lohbauer et al., 2008; Flury et al., 2010; Da Silva et al., 2014; Da Silva et al., 2015; Vichi et al., 2018). Several polishing protocols are available to reduce irregularities that arise during the adjustment of ceramic restorations and obtain a smooth, polished surface. These protocols include diamond points of different grits, sandpaper, abrasive rubbers, polishing tips, or pastes (Flury et al., 2010; Da Silva et al., 2015; Mohammdibassir et al., 2019; Sasany et al., 2022).

From a biological point of view, ceramic restorations must have smooth surfaces to increase the restored tooth's longevity (Flury et al., 2010; Da Silva et al., 2015; Vichi et al., 2018; Lu et al., 2023). Furthermore, smooth surfaces obtain better mechanical properties, avoiding antagonist wear and minimizing the accumulation of bacterial biofilm, gingivitis, and the risk of compromise by secondary caries (Alao et al., 2017; Vichi et al., 2018; Mohammadibassir et al., 2019; Monaco et al., 2014; Brodine et al., 2021).

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The roughness of finished and polished surfaces significantly affects ceramics' stress concentration and fracture resistance (Mohammadibassir et al., 2019; De Jager et al., 2000; Matzinger et al., 2018). The material's properties and resistance depend on the surface's roughness and topography, and a rough surface can cause cracks or further propagation. Polishing accompanies an increase in toughness and fracture resistance, avoiding surface flaws and contributing to the fracture resistance of the restoration (Mohammadibassir et al., 2019).

Surface profilometry is a suitable method for quantitatively evaluating surface roughness (Amaya Pajares et al., 2016; Mohammadibassir et al., 2019). Previous studies conventionally measured surface roughness with a profilometer on flat specimens (Fraga et al., 2015; Da Silva et al., 2015; Amaya Pajares et al., 2016; Madruga et al., 2019; Brodine et al., 2021; Sasany et al., 2022; Kulvarangkun et al., 2022).

Therefore, the objective of the present study was to investigate, through *in vitro* tests, the effect of a finishing and polishing protocol on the surface roughness of overlays made from milled lithium disilicate, simulating clinical conditions. The surface roughness and the morphology of the different occlusal areas (external slope - ES, internal slope - IS, and fossa - FO) were evaluated separately after glazing, finishing, and polishing.

The null hypothesis was that there would be no significant differences in surface roughness among the three groups representing different surface treatments (glaze, finishing, and polishing) considering three different areas of the restorations.

MATERIALS AND METHODS

SAMPLE SIZE CALCULATION

An effect size of 0.3 and a standard deviation of 0.2 were estimated based on a pilot study. These values were input into the G*Power software (ver. 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) together with an alpha-type error rate of 5% and a beta power of 80%. The software indicated six samples per group.

SAMPLE PREPARATION

To carry out this laboratory study, tooth 46 from a dental mannequin (Pronew Odonto, Rio de Janeiro, Brazil) was used to prepare an all-ceramic overlay. The Trios 3 intraoral scanner (3Shape, Copenhagen, Denmark) scanned this preparation, enabling the obtaining of samples via digital flow. With the help of Cerec Inlab software (Dentsply Sirona,

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Bensheim, Germany), we designed the restoration project, which was saved in Standard Tessellation Language (STL) format and exported to the MC XL milling machine software (Dentsply Sirona, Bensheim, Germany) for the preparation of the test specimens. The milled material was lithium disilicate IPS e.max CAD Cerec Inlab (LT D3, Ivoclar Vivadent AG, Schaan, Liechtenstein), provided by the company. In total, six identical restorations were created (N=6).

After milling, all samples underwent the crystallization process (20 minutes at 840ºC, Multimat NTX oven, Dentisply Sirona, Bensheim, Germany) and glazing (IPS Ivocolor Glaze Fluo, Ivoclar Vivadent AG, Schaan, Liechtenstein) for 8 minutes at 800ºC in the Multimat NTX oven (Dentisply Sirona, Bensheim, Germany), according to the manufacturer's recommendations. The materials used in this study are specified (brand, manufacturer, composition) in Table 1.

TABLE 1 – Materials used in the research

Material	Manufacturer	Composition
Diamond point	American Burrs, Palhoça – SC, Brasil	Fine (F) and extrafine (FF) diamond particles
IPS emax CAD (LT D3)	Ivoclar Vivadent AG, Schaan, Liechtenstein	Dissilicato de lítio (SiO2, LiO, K2O, PO, Zr2O3, ZnO2, AlO, Mg2O3)
Kit Optragloss	Ivoclar Vivadent AG, Schaan, Liechtenstein	Diamond, polyurea titanium dioxide; (Spiral wheel: phthalic diacrylic acid ester and cotton cellulose).
Temp-Bond NE	Kerr Corporation, Califórnia, Estados Unidos.	Zinc oxide-based cement, without eugenol.

FINISHING AND POLISHING MANEUVERS TESTED

Three specific areas of the occlusal surface of a ceramic overlay of a lower first molar were selected, representing areas of different access difficulties for the finishing and polishing procedures. These regions are depicted in Figure 1, showing the external smooth slope (ES), internal grinding slope (IS), and fossa (FO), the area between the proximal fossa and the marginal ridge, respectively. The ES, IS, and FO regions were evaluated after three treatments: glaze (G), finishing (F), and polishing (P).

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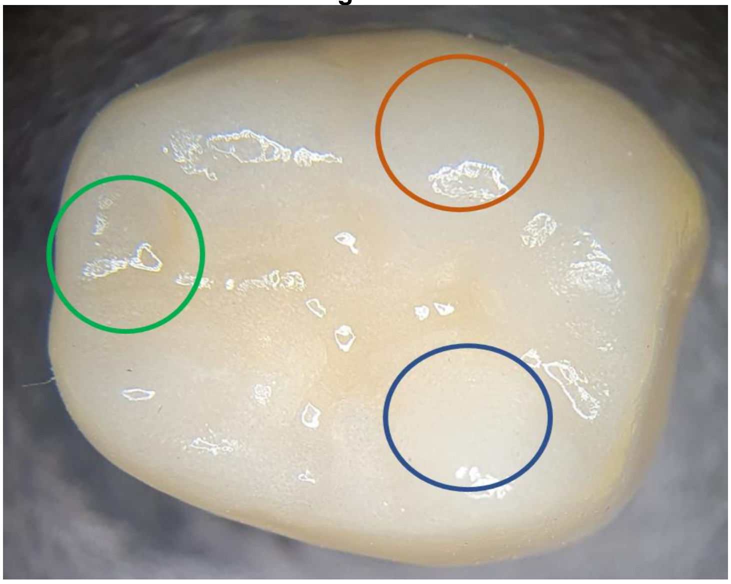
Figure 1



To standardize the region to be finished and polished, an acetate matrix was made on the overlay with circular holes with a 2 mm diameter, verified with a digital caliper (Mitutoyo Digital Caliper 500-196-20B, Mitutoyo Sul Americana, São Paulo, Brazil). We used the matrix to check the region during all finishing and polishing procedures. During the finishing process, the operator used a permanent felt-tip pen (Pilot, black, São Paulo, Brazil) to mark the area for adjusting with the diamond point. During polishing, a visual inspection was performed on the finished area. A single, previously trained, calibrated operator performed all finishing and polishing procedures regarding the pressure used during polishing after training in simulated procedures on lithium disilicate fragments, performed on a precision scale corresponding to a pressure of 20 g. Considering the difficulties in accessing the restorations (intrinsically related to the simulation of the clinical situation), we did not impose time restrictions on the finishing and polishing procedures, using the following parameters for the polishing systems: force compatible with a pressure of 20 g and a speed of 10,000 rpm (standardized by an electric motor). The procedures were performed individually, with each overlay positioned on a dental mannequin, attached to an adapted doll (Bob Simulator, Pronew Odonto, Rio do Ouro, São Gonçalo, RJ, Brazil). The overlays were cemented with Temp-Bond NE temporary cement (Kerr Corporation, California, United States) to simulate clinical conditions and prevent overlay movement during the treatment. The finishing stage sought to simulate an occlusal adjustment, using oval-shaped diamond burs, 3168, with fine grain size (F) (grain size of 46 µm) and extra fine (FF) (grain size of 30 µm), respectively (American Burrs, Palhoça – SC, Brazil), with

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water cooling spray, at high speed (KaVo, Biberach, Germany) for 15 seconds each. The OptraGloss kit (Ivoclar Vivadent AG, Schaan, Liechtenstein) was used in the polishing stage. This system comprises rubber polishers with different shapes and consists of two stages for the polishing process. The first stage is pre-polishing in the shape of a cup, flame, or disc with a dark blue color. The second stage is high-gloss polishing, available in a cup, flame, disc, or spiral wheel shape (with a light blue color).

Polishing was performed immediately after the finishing process with an adjustable low-speed electric handpiece (KaVo, Biberach, Germany) that was mounted on an LB100 benchtop micromotor (Beltec, Araraquara, SP, Brazil) to ensure standardized test conditions with a rotation speed of 10,000 revolutions per minute (rpm). Each area was assigned a specific polishing shape. Thus, the cup shape was used for the external slope, the disc shape for the internal slope, and the flame shape for the fossa. There is no specific manufacturer's recommendation. The restorations were water sprayed for 10 s after each finishing and polishing step to remove debris and dried with an air jet for 10 s before the following step.

PROFILOMETRY ANALYSIS AND IMAGE ACQUISITION

In this study, contact surface profilometry was used to assess surface roughness and perform morphological analysis using a roughness and shape measuring device (Taylor Hobson PGI830 with Ultra software, version 5.14.9.70) from the Biomaterials and Tribology Laboratory (Materials Metrology Division, National Institute of Metrology, Quality and Technology - INMETRO, Duque de Caxias, Rio de Janeiro, Brazil).

Contact profilometry analysis can be performed in each specific region due to the overlay's fixation in three condensation silicone indexes (Perfil, Coltène, SP, Brazil) with different positions for each area, facilitating access to the probe. A parallelometer was used to fix the samples in the silicone index, making the analyzed region as perpendicular as possible with respect to the profilometer's active tip.

The average roughness (Ra) parameter was evaluated three times, generating three distinct groups. Initially, the glazed overlays were read as the sample arrived from the laboratory. Two more readings were subsequently taken, one after the finishing step and another after the polishing step. The area scanned by the profilometer was defined by the acetate matrix with holes, circumscribing the glazed, finished, or polished areas in the different regions, external slope, internal slope, and fossa.

The acquisitions of three-dimensional (3D) images were generated from the reading of each region of the sample, measuring the data length in (x) 1.2 mm and the data length in (y) 1.2 mm, with a spacing in (y) of 0.1 mm. The method generated 100 profiles at a speed of 0.5 mm/s. The profile measurements were taken with a 90º conical probe and a diamond tip with a diameter of 4 µm.

The analyses of the 3D images and roughness profiles were performed using Talymap software (version 4.1.2.4434, Mountains software, Digital surf, Besançon, France), which uses ISO 4287 to measure the Ra parameter. It was necessary to remove the surface shape using a polynomial order ranging from 3 to 5 so that only the values of the micro heterogeneities were computed, “erase defects” was used, when necessary, to eliminate surface defects not created by the finishing or polishing methods, and subsequently “the extraction of a series of profiles”, utilizing a sampling length (cut-off) of 0.25 mm, generating an average Ra value from the 100 extracted profiles. All analyses were performed by a trained and calibrated operator, blinded to the groups.

STATISTICAL ANALYSIS

Normal distribution and homoscedasticity of the data were checked with the Shapiro–Wilk and Kolmogorov-Smirnov tests. All data displayed a parametric (normal) distribution. Statistical analysis was performed by SPSS 23.0 for Windows (SPSS Statistics, version 23; IBM Corp., USA). Two-way repeated-measures ANOVA was used to show the effect of different surface treatments (glaze, finishing, and polishing), considering three distinct areas of the restorations (ES, IS, and FO). Bonferroni’s adjustment for multiple comparisons was used. The significance level was set at $p \leq 0.05$.

RESULTS

Means and standard deviations of roughness values for the different tooth areas in all different surface treatments were calculated and presented in Table 2. There were significant differences among the levels of the factors “tooth area” ($p = .049$), “surface treatment” ($p < .00$), and in the interaction between factors ($p < .00$). Considering the three surface areas, after the different treatments, group FO presented significantly higher roughness when polished than the other groups ($p < .05$). Considering the various surface treatments, significant statistical higher roughness was observed in group FO.

TABLE 2 - Mean (SD) of the Ra values (mm), concerning the surface roughness of the different surface treatments at each tooth area.

Experimental treatments	Fossa	Internal Slope	External Slope
Glaze	0,24 (0,15) Aa	0,34 (0,13) Aa	0,22 (0,13) Aa
Finish	0,89 (0,48) Ba	0,72 (0,13) Ba	0,74 (0,18) Ba
Polish	0,61 (0,29) ABa	0,21 (0,06) Ab	0,14 (0,06) Ab

Note: In columns, different capital letters indicate significant differences among surface treatment groups, within the tooth area ($p < .05$). In rows, different lowercase letters indicate significant differences among different tooth areas, within the surface treatment groups ($p < .05$).

DISCUSSION

Even considering that dental surfaces present significant anatomical variations, with concave and convex areas, most *in vitro* studies evaluate the finishing and polishing protocol of lithium disilicate (as well as other restorative materials) on flat samples (Fraga et al., 2015; Da Silva et al., 2015; Amaya Pajares et al., 2016; Madruga et al., 2019; Brodine et al., 2021; Sasany et al., 2022; Kulvarangkun et al., 2022). Therefore, possibly the most striking contribution of this study is to evaluate the surface roughness in different regions (ES, IS, and FO) of a ceramic restoration after several treatments (G, F, and P) on surfaces homologous to natural teeth, positioned on dental mannequins to simulate clinical conditions of an occlusal adjustment. Based on the results of this study, the null hypothesis that the intraoral polishing protocol used in the samples would not present statistically significant differences in surface roughness through the analysis of the mean roughness parameter (Ra) in lithium disilicate concerning glaze was partially rejected, considering statistically significant differences for the FO region.

The statistically significant difference between the finishing (F) and polishing (P) demonstrates the effectiveness of polishing in reducing the surface roughness of lithium disilicate overlays, which agrees with the existing literature (Lohbauer et al., 2008; Da Silva et al., 2014; Sarikaya & Guler et al., 2010; Dutra et al., 2018). According to Fahmy et al. (2009), polishing can reduce surface flaws, prevent the distribution of cracks, and increase the fracture resistance of the restoration. The literature shows several *in vitro* studies evaluating the effects of different finishing and polishing techniques on the surface roughness of ceramic materials on flat specimens. Some studies indicate that glazed surfaces are qualitatively better than polished surfaces (Al-Shammery et al., 2007; Perez et al., 2009; Amaya Pajares et al., 2016; Brodine et al., 2021). However, other studies show the opposite results, with Ra values for polishing lower than for glazing (Flury et al., 2010; Mohammadibassir et al., 2019; Kulvarangkun et al., 2022). Furthermore, some studies describe polished and glazed surfaces as equivalent (Bottino et al., 2006; Sarac et al., 2006; Al-Wahadni et al., 2006; Vichi et al., 2018). This heterogeneity demonstrates that the quality of ceramic polishing methods is still controversial in the literature. The findings of this study corroborate the studies that presented equivalence since the three methods were statistically equal.

This study showed that group P presents similar roughness to group G when considering areas more accessible to polishing instruments. Group G showed lower roughness results than P only when considering the FO region, which brings intrinsic accessibility difficulties.

Profilometry is an objective and efficient method for measuring surface roughness that allows quantitative evaluation of surface roughness *in vitro* (Van Dijken et al., 1987; Amaya Pajares et al., 2016; Mohammadibassir et al., 2019). Profilometers have been used to determine several roughness parameters, such as the Ra, the most used to evaluate surface roughness in ceramics (Vichi et al., 2018), defined as the average absolute deviation of roughness irregularities from the mean line along a sampling length (Al Shammery et al., 2007). However, the Ra value represents the average roughness of the sample without considering the occurrence of an atypical peak or valley on the surface (Perez et al., 2009). If this occurs, the results have no significant influence since the average value does not undergo many changes and can hide probable surface defects (Silva et al., 2019). Because of this, this study also qualitatively analyzed the 3-D images obtained by the Talymap software after glazing, finishing, and polishing procedures.

Figures 2 and 3 show the differences in roughness between the FO and ES regions, highlighting the surface topography's complexity and the need for specific strategies for different areas. The FO area, with higher Ra values in all procedures, may be more challenging due to its morphologically complex nature, which is a relevant finding with possible clinical implications.

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Figure 2 – FO region with 3-D images and roughness profile

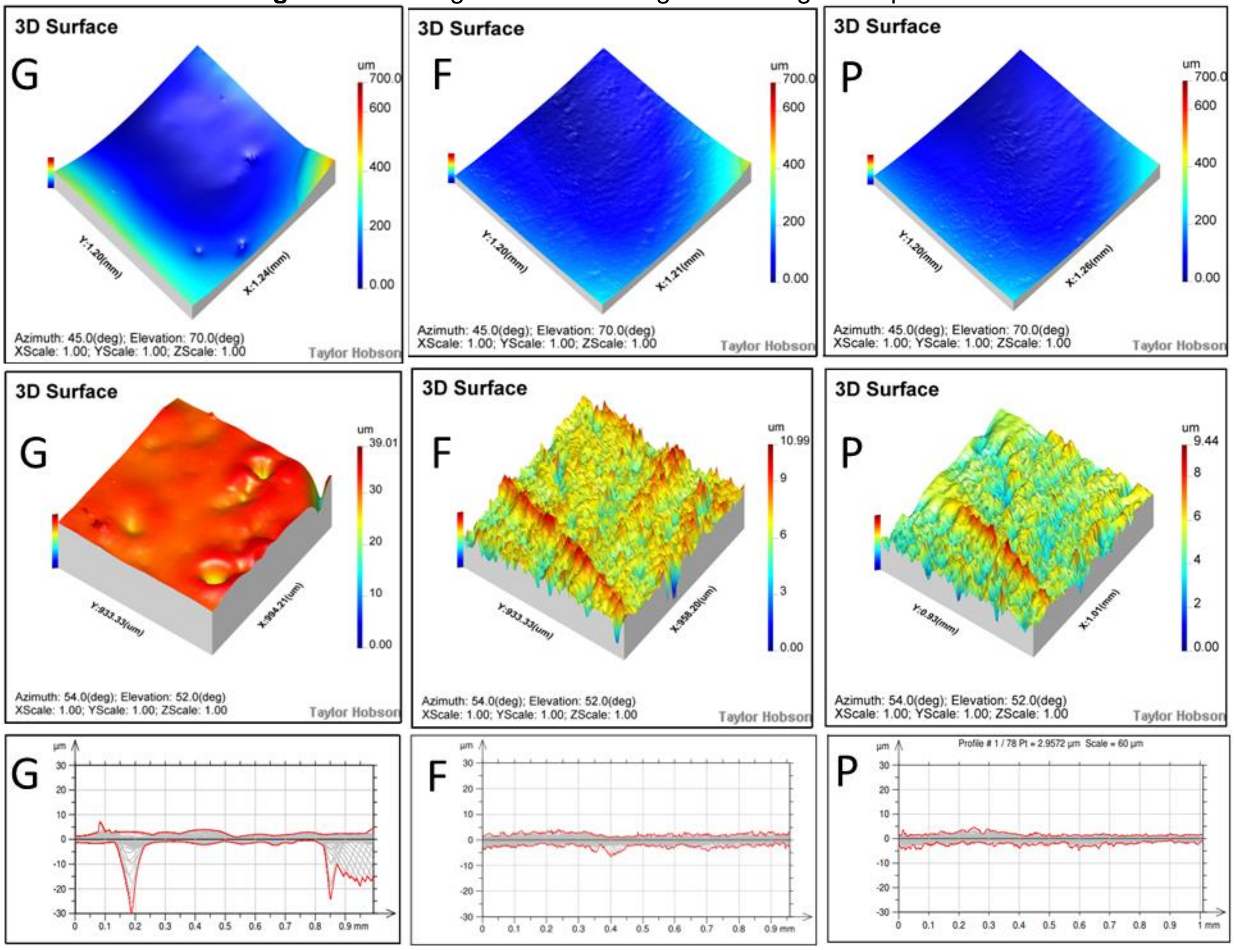
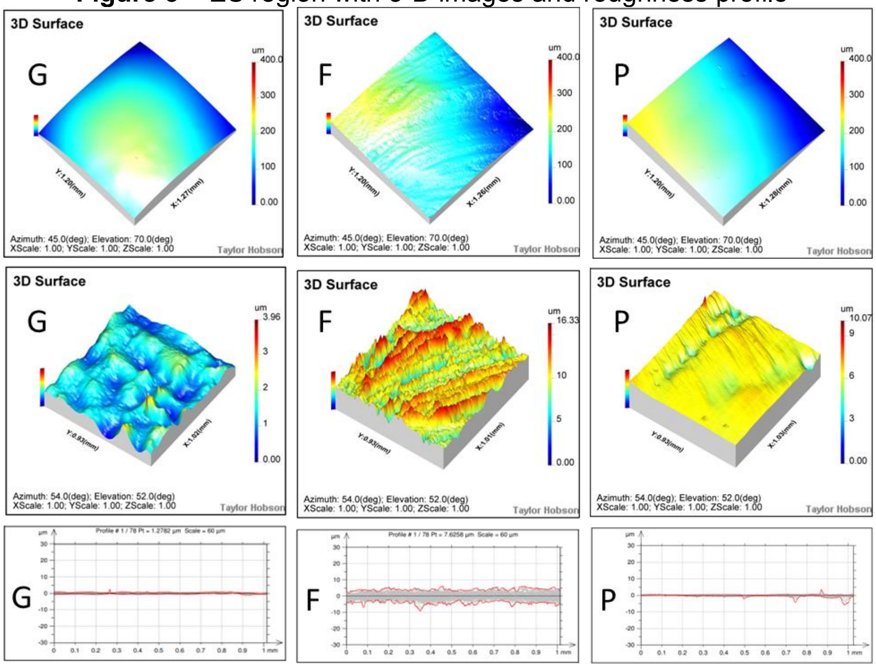


Figure 3 – ES region with 3-D images and roughness profile



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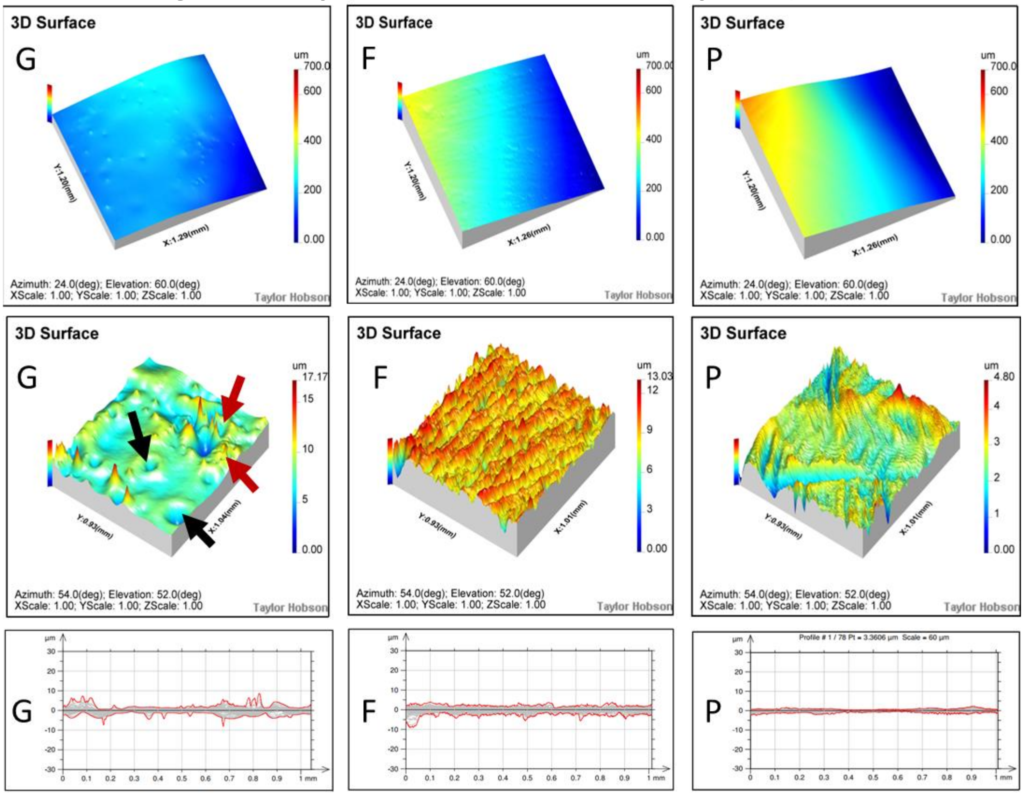
The ES region, presenting the lowest Ra values, confirms that this area is more easily accessible by glazing and intraoral polishing with rubbers. Its suggests that professionals can achieve more satisfactory polishing results in this region because of its convex and more regular surface (Figure 3). In addition, it is not a region with high masticatory demand, which reduces the fracture risk. The surface roughness of ceramics significantly influences bacterial adhesion and plaque accumulation. The literature shows that the limiting roughness of intraoral surfaces to avoid bacterial colonization considered clinically acceptable is approximately 0.2 µm (Bollen et al., 1997; Heitze et al., 2005). In the present study, the ES and IS regions presented Ra values close to this limit. Furthermore, the tongue can detect the roughness of a restoration in the range of 0.25 – 0.5 µm (Jones et al., 2004) considering the results of this study and the occlusal surface of a DL restoration, the polished FO region would have a surface roughness sensitive to the perception of the tongue, and its values can be comparable to the polishing of a feldspathic ceramic after a glaze procedure (0.6319 ± 0.1145 µm) in the study by Kulvarangkun et al. (2022), which evaluated the surface roughness of three dental ceramics after polishing with three extraoral polishing sets.

Figure 4 – Region IS with 3-D images and roughness profile



Legend: Black arrow indicates bubbles and pores, red arrow indicates micro irregularities

The literature reports that glazing is a polishing step that corresponds to a thin layer of ceramic with a lower melting point to obtain a highly polished surface, being applied to the surface of the ceramic restoration, helping to achieve surface smoothness and shine, promoting the sealing of surface defects and residual compression stresses (Anasuvice et al., 2021). Through the qualitative analysis of the 3-D images obtained, it is suggested that the flatter areas allow a better flow of this glaze layer, for example, in ES (Figure 3). At the same time, regions with diverse anatomy may present alterations such as microbubbles and micro irregularities, as seen in IS, which leads us to conjecture that the irregularities in this region hinder the flow of this laboratory polishing (Figure 4), being clinically relevant because it is considered a region of masticatory load.

In their study, Lien et al. (2015) reported that pores on the surface of IPS e.max CAD occur due to highly soluble spherical lithium phosphate crystals removed during milling the intermediate phase of lithium disilicate. These pores can cause stress concentrations during masticatory force, weakening the mechanical properties of LD restorations (Lu et al., 2023). Analyzing the 3-D profilometry images that show surface roughness, it is possible to identify the presence of these pores in greater quantity in the FO followed by IS, thus indicating that different occlusal regions manifest differences in the condition of the ceramic surface and, therefore, the ability to resist crack propagation, revealing that both its longevity and its wear potential should be evaluated and further investigated.

This study has intrinsic limitations, such as the choice of a single type of ceramic and the application of a single polishing technique.

Thus, this study should lead to new approaches to the subject, such as comparing the application of glaze after milling and after finishing maneuvers and the effect of different roughness levels obtained in different regions on the wear of the antagonist. In addition, other roughness parameters should also be analyzed to calculate differences between peaks and valleys, the spacing between them, and the shape of the profiles and their relevance discussed in more depth.

CONCLUSION

Finishing and polishing procedures are widely used in clinical practice and require our attention regarding their effectiveness in the different regions of ceramic restoration. Although in vitro studies demonstrate adequate roughness after mechanical polishing, these studies were carried out on flat specimens. In this work, three specific areas of the occlusal surface of a ceramic overlay of a lower first molar were selected, representing areas of different access difficulties for finishing and polishing procedures. The significantly greater roughness values obtained after polishing the fossa (a non-flat region with high masticatory demand) allow us to assume that access to polishing instruments is limited in this region, preventing efficient action and, in some cases, indicating a new application of glaze to correct the superficial defects produced after occlusal adjustment.

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