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Research Article

Surface Roughness Evaluation of Resin Composites after Finishing and Polishing Using 3D-Profilometry

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The purpose of this study was to evaluate the effect of two finishing and polishing methods on the surface roughness of different resin composites. Twenty-two disk-shaped specimens of five resin composites Zirconfill® (ZF), Filtek™ Supreme XTE (FS), Brilliant EverGlow™ (BG), Ceram.X® Duo (CD), and Harmonize™ (HA) were prepared for each one using a silicon mold. Both surfaces of each specimen were first grinded with 600-grit silicon carbide paper in a moistened environment. The polishing methods used included the two-step Enhance® and PoGo® polishing system (E/P) or the four-step SwissFlex® discs (SFD). Surface roughness was evaluated using a noncontact 3D-optical profilometer. Surface morphology was examined by scanning electron microscopy. Data were analyzed using two-way analysis of variance and pairwise comparisons with Tukey's test ($\alpha = 0.050$). Surface roughness was affected by both the type of resin composite ($p < 0.001$) and the finishing and polishing system ($p < 0.001$), with a significant interaction between these two factors ($p = 0.025$). The E/P system produced smoother surfaces than the SFD system ($p < 0.001$). For the E/P system, the highest mean roughness value was obtained with ZF and was statistically different from all other composites, whereas inhomogeneous results among resin composites could be found for the SFD system. Surface roughness was material-dependent, and the polishability of the resin composites was best accomplished using the E/P system. Within each F/P system studied, BG showed the lowest average surface roughness and ZF registered the highest.

1. Introduction

Resin-based composites (RBCs) have been progressively used for different applications in dentistry, particularly in restorative procedures, as they provide good esthetic properties, ease of handling, and long-term clinical performance [1–3]. Nevertheless, surface and optical characteristics, such as color stability, surface gloss, and smoothness, can significantly influence the clinical success and longevity of these restorations [4].

Basically, RBCs are composed by a polymeric organic matrix, an inorganic portion, a silane agent, and polymerization initiators. Resin composites can be classified according to the average size, content, and type of filler particles [5–7]. These materials have evolved from macrofilled, containing particle sizes between 10 and 50 μm, ensuring good mechanical strength but poor finishing and polishing quality. On the contrary, microfilled RBCs, with a particle size between 0.01 and 0.04 μm, exhibit high polishability. Then, intermediary-size particles (0.6–1 μm) were incorporated into composites. These materials improved to microhybrids (0.01–3 μm), providing higher mechanical properties combined with better surface features [5, 6, 8, 9]. More recently, nanofilled composites containing a fraction of nanoparticles (<100 nm) and submicron particles averaging less than 1 μm (0.5–1 μm) were developed and aimed to provide superior esthetics, as well as good mechanical properties, allowing them to be used for both posterior and anterior restorations. Some of these materials include nanoparticles and/or prepolymerized filler agglomerates (0.4–5 μm) in composites and were called nanohybrids [8, 10, 11].

In dental practice, creating smooth surfaces has always been one major objective of composite restorations, not only for esthetic reasons but also regarding better oral health of soft tissues and marginal integrity of the restorative interface. Finishing procedures are performed to remove surface excesses around restorations while achieving an adequate final contouring and anatomy, and polishing reduces surface roughness and fine scratches originating from finishing, aiming to create a smooth surface with high luster and brightness similar to natural enamel [3, 8, 12–14].

The roughness of a composite resin surface depends on their chemical composition and mechanical characteristics, which are mainly determined by the size, shape, and percentage of inorganic filler particles [15–18]. As the size of filler particles decrease and the percentage by weight increase, the surface properties and polishing features of a material improves [1]. Increased surface roughness can induce discoloration, staining, and loss of gloss [8, 10, 19], along with a bio-sourced layer retention in niches where microorganisms are protected from shear forces and salivary flow [18]. It has been reported that a material should maintain a surface roughness (R_a) value below 0.2 μm in order to reduce susceptibility to surface plaque accumulation, caries development, and periodontal inflammation. More recent research stated that the impact of roughness on bacterial adhesion seems to be related not to a roughness threshold but rather to a range. The range of surface roughness among different finishing/polishing methods is wide and material-dependent, and each dental material requires its own treatment modality to obtain and maintain a surface as smooth as possible [18]. However, a controversial topic about the best techniques or materials to be used is still relevant because different polishing systems yield dissimilar outcomes on resin composite surfaces [1, 4, 8, 10, 17].

Characterization of the surface texture of composites has become extremely important because it is well-known as it behaves as a key-factor affecting clinical function. Measurement and analysis of the surface of composites provide an important diagnostic tool for comparing either composite material and the process that produces the final polished surface [20]. Different *in vitro* methods were used to evaluate the surface roughness of resin composites, including mechanical and 3D-optical profilometry for quantitative analysis and scanning electron microscopy (SEM) for qualitative assessments. Existing literature is scarce on surface roughness analysis using optical 3D profilometer. This profilometer uses an optical beam that provides a 3D analysis with both qualitative and quantitative representation, thus giving details about the shape of the roughness that may also be relevant for bacterial adhesion other than just the magnitude of R_a [21]. Besides providing different parametric values, the 3D-profilometry advantageously allows a detailed visual description of the surface roughness profile of the composite [8, 14, 22, 23].

A variety of one- or multistep finishing and polishing systems for resin composites are available, differing in the presentation, composition, type, and hardness of the abrasive particles. The most common instruments used for finishing and polishing restorative materials include carbide finishing burs, diamond finishing burs, rubber cups, and points, disks, abrasive strips, and polishing pastes. Aluminum oxide, silicon carbide, and diamond are the most used particles impregnated or coated in these systems, which are preferably used in a predefined descending sequence of grain size in multistep systems [12, 24–26]. The effect of the finishing/polishing systems on the surface roughness of composites has been reported to be material-dependent, and the effectiveness of these systems was mostly product-dependent, being that multistep systems provide better performance [4, 18]. In addition, surface anatomy and adequate handling may also impact composite polishing [15, 27].

The aim of this study was to evaluate the surface roughness of five resin composites using optical 3D-profilometry and SEM after using two finishing and polishing systems.

The main null hypothesis is that there are no differences in surface roughness values between the five composite resins for each finishing and polishing system. The secondary null hypothesis was that there are no differences in surface roughness between both finishing and polishing systems tested for each composite resin and that there is no interaction among the variables composite resin and system used.

2. Materials and Methods

2.1. Preparation of Composite Resin Specimens. Five marketed and existing RBCs were evaluated in the present study: Zirconfill® (TECHnew, RJ, Brasil); Filtek™ Supreme XTE (3M ESPE, St Paul, MN, USA); Brilliant EverGlow™ (Coltène, Whaledent, Altstätten); Ceram.X® Duo (Dentsply DeTrey, Konstanz, Germany) and Harmonize™ (KERR, Orange, CA, USA) (Table 1). For all resin composites, an enamel shade A2 was selected. Twenty-two disk-shaped specimens were prepared for each resin composite using a silicon mold with a diameter of 6 mm and a thickness of 1.5 mm. The composite resin was condensed in a single increment, and the upper and bottom surfaces of the mold were covered by 1 mm thickness glass slides where the material was compressed under pressure to produce a smooth surface while reducing the incorporation of pores into the formed resin disc. The composite was light-cured from both sides for 40 s each using a light emitting diode (LED) curing unit (SPEC 3 Coltène LED, Whaledent, Cuyahoga Falls, OH, USA) emitting an irradiance of 1,600 mW/cm^2 by placing the tip into direct contact with the glass slide. Afterward, each specimen was removed from the mold and stored in distilled water at 37°C for 24 hr. Both surfaces of each specimen were first grinded with 600-grit SiC sandpaper (WSFlex 16®, Hermes Schleifmittel GmbH, Hamburg, Germany) in a moistened environment for 10 s to reach a standard surface roughness level prior to the finishing and polishing

Table 1: Type and composition of the materials according to manufacturers' information.

Group	Product (abbreviation) composite type	Filler type composition filler (%) wt/vol	Matrix	Manufacturer lot number
1	Zirconfill® (ZF) Nanohybrid	Diatomite; silica; mixed oxide of zirconia and silica; barium glass 80/-	Bis-GMA; Bis-EMA; TEGMA; UDMA	TECHnew, RJ, Brasil 16003
2	Filtek™ Supreme XTE (FS) Nanofilled	Aggregated zirconia/silica cluster filler (0.6–10 μm); silica (20 nm); zirconia (4–11 nm) 78.5/63.3	Bis-GMA; UDMA; TEGDMA; bis-EMA	3M ESPE, St Paul, MN, USA N843006
3	Brilliant EverGlow™ (BG) Nanofilled	Prepolymerized filler with glass and nano-silica; colloidal nanosilica aggregated and barium glass nonaggregated (0.02–1,5 μm) 74/56	Bis-GMA; Bis-EMA; TEGDMA	Coltène/Whaledent AG, Altstätten, Switzerland H31783
4	Ceram.X® Duo (CD) Nanofilled	Barium-aluminium-borosilicate glass (1.1–1.5 μm); nanofiller (10 nm) 76/57	Methacrylate Modified Polysiloxane; Bis-GMA; TEGMA	Dentsply DeTrey, Konstanz, Germany 0784
5	Harmonize™ (HA) Nanohybrid	Barium-aluminum-borosilicate glass (mean particle size 0.4 μm); aggregated zirconia/ silica cluster filler (2–3 μm) 81.5/64.5	Bis-GMA; Bis-EMA; TEGDMA	KERR, Orange, CA, USA 6280026

Bis-GMA: bisfenol-A glycidyl dimetacrylate; Bis-EMA: bisfenol-A ethoxylated dimetacrylate; UDMA: urethane dimetacrylate; TEGDMA: triethylene glycol dimethacrylate; TEGMA: triethylene glycol monomethacrylate.

Table 2: Finishing/polishing systems used in this study.

Material (abbreviation)	Composition and abrasives		Type	Manufacturer
Enhance® PoGo® (E/P)	Polymerized urethane dimethacrylate resin and silicon dioxide	40 μm aluminum oxide 7 μm fine diamond powder	Two-step rubber finishing and polishing	Dentsply DeTrey, Konstanz, Germany
SwissFlex™ (SFD)	Thin, transparent disks that are selectively coated with aluminum oxide particles. The coarse disc is completely coated on the upper side with black silicon particles	Aluminum oxide (coarse, medium, fine, ultra fine)	Four-step rubber polishing discs	Coltène/Whaledent AG, Altstantten, Switzerland

procedures. They were thoroughly rinsed with combined air and water spray afterward. The specimens were handled using tweezers to protect the flat surface of the composite from any damage or contamination.

2.2. Finishing and Polishing Procedures. The specimens of each composite were randomly divided into two groups to be submitted to the finishing/polishing procedures, each comprising 10 specimens ($n = 10$). A two-step rubber finishing and polishing system Enhance®/Pogo® (Dentsply DeTrey, Konstanz, Germany) and a four-step rubber polishing discs SwissFlex™ (Coltène/Whaledent AG, Altstätten, Switzerland) were selected for the present study (Table 2). Two specimens of each resin composite were reserved and used to characterize resin composite surface morphology. Each sample was submitted to the finishing and polishing procedures according to the manufacturer's instructions regarding speed, pressure, and water need. A slow-speed handpiece was coupled to individualized support in order to standardize the pressure and maintain a perpendicular position on the surface of specimens (Figure 1). A chronometer was used to control the time for each system step. The specimen preparation, finishing, and polishing procedures were carried out by the same operator.

Single-use rubber discs of Enhance® Finishing System and PoGo® Polishing System (Dentsply DeTrey, Konstanz, Germany) were used as follows: the specimens were primarily dry-finished, according to the manufacturer's instructions, for 30 s with Enhance® disc points at 7,000 rpm 1 : 1, rinsed with distilled water to remove debris during 5 s and then air-dried. The specimens were then dry-polished with PoGo® disc points at 7,000 rpm 1 : 1 for 30 s, rinsed with distilled water, and then air-dried.

Single-use SwissFlex® (Coltène/Whaledent AG, Altstätten, Switzerland) discs were used in a descending sequence of grain size, from coarse (70 μm), medium (50 μm), fine

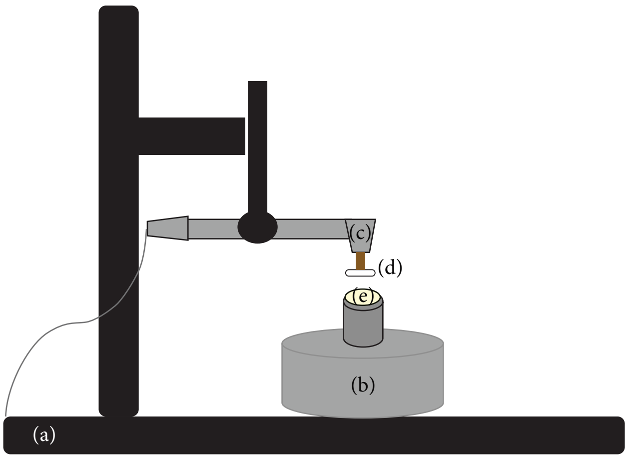


Figure 1: Schematic illustration of finishing and polishing procedures: (a) individualized support; (b) specimen support; (c) slow-speed handpiece; (d) finishing and polishing system; (e) specimen.

(30 μm), and extra-fine (5 μm) as follows: the first two discs were applied underwater with a constant one-directional movement at 7,500 rpm 1 : 1 for 20 s and the last two discs for 40 s. Surfaces were rinsed thoroughly under water during 5 s between each grit disc.

After this process, all samples were placed in an ultrasonic bath (BioSonic® UC150, Coltène/Whaledent AG, Altstätten, Switzerland) for 5 min to eliminate debris and stored in distilled water at 37°C for 1 week prior to evaluation.

2.3. Surface Roughness Measurement. A noncontact 3D optical profilometer (S neox® 3D, Sensofar, Barcelona, Spain) was used to measure the surface roughness in S_a, which is a 3D-parameter expanded from Ra (2D) parameter as given by ISO standard 25178. S_a (μm) parameter expresses the mean of the absolute values of roughness in the measured area. S_z, S_v, S_p, and S_{sk} roughness parameters variations for each resin composite according to the finishing and polishing system procedure were also obtained from the same topographic measurements. An overview of the surface was made initially on the center of the discs with a 10x magnification in an area of $6.49 \times 7.26\,mm^2$ with four columns and six lines to identify the locations for the analysis. For determination of the surface roughness, four random sites on the sample surface were selected, and four images were obtained with the 100x objective in confocal mode. Each sample corresponds to an area of $175.4 \times 132.1\,\mu m^2$ (Figure 2), and the mean values of the roughness parameters were calculated.

2.4. Surface Morphology Evaluation. Both untreated specimens of each resin composite were chosen for qualitative analysis. The samples were dehydrated using increasing ethanol sequences and immersed for 2 min in each solution (60%, 80%, 90%, 100%) in ultrasonic cycles (BioSonic® UC150, Coltène/Whaledent AG, Altstätten, Switzerland). Samples were placed on metal stubs, sputter-coated with gold and palladium, and examined under an SEM (Hitachi S-4100, Hitachi High Technology Corp., Tokyo, Japan) with an accelerating voltage of 25 kV for surface morphology evaluation. SEM photomicrographs of representative surface areas were observed at 500x, 2,500x, and 5,000x magnifications.

2.5. Statistical Analysis and Sample Size. Statistical analysis was performed with IBM® SPSS® Statistics Version 26. Two-way analysis of variance (ANOVA) was used to determine an interaction between the resin composite and the type of F/P system on S_a results and the main effect of each of those factors. Since a disordinal interaction was found between the two factors and there was a violation of the assumption of homogeneity of variances, simple main effects for the F/P system factor and the resin composite factor were carried out using Welch ANOVA and post hoc comparisons with Games–Howell corrections. The level of significance was set at 0.05 for all analyses.

The total sample size was determined using G *Power version 3.1.9.6 considering the two-way ANOVA option with the factors composite resin and polishing system presenting 5 and 2 levels, respectively, and a total number of groups of 10. The computation of the required sample size used a significance level of (α) 0.05 and statistical power ($1-\beta$) of 0.8, with a conventional large effect size (f) of 0.4. Under these conditions, the minimum required total sample size was 80.

3. Results

Mean values and standard deviations (s.d.) of surface roughness are presented in Table 3.

Two-way ANOVA showed that surface roughness of the samples was affected by both the type of resin composite ($p<0.001$) and the finishing and polishing system ($p<0.001$), with a significant interaction between these two factors ($p = 0.025$) indicating that F/P systems do not induce the same results in the different resin composites studied. There is significant evidence that the degree of roughness is influenced by the F/P method, with the highest roughness being associated with the use of SFD for all resin composites ($p<0.001$). Pairwise comparisons between S_a values of resin composites finished and polished with the both systems can be found in Table 3. For the SFD system, surface roughness results are not homogeneous among the different resin composites, with ZF and FS presenting the highest and statistically similar values ($p = 0.729$) and BG and CX presenting the lowest and non-statistically different surface roughness values (0.371). On the contrary, the use of the E/P system produces the highest S_a mean value in ZF, which is statistically different from all the other composites FS ($p = 0.043$), BG ($p<0.001$), CX ($p = 0.018$), and HA ($p = 0.004$).

Additional roughness parameters (S_z, S_v, S_p, and S_{sk}) that further help understanding the behavior for each resin composite and polishing system studied can be visualized in Figure 3. The S_z parameter, despite being larger by a factor of 10, showed a similar trend as S_a for the surfaces of all materials finished with both the E/P and SFD polishing systems. The S_v and S_p values used to obtain S_z also help having a clearer picture of the surface features. A direct comparison of S_v and S_p for both polishing systems reveals that, as a rule, SFD induces valleys that are deeper than the height of the

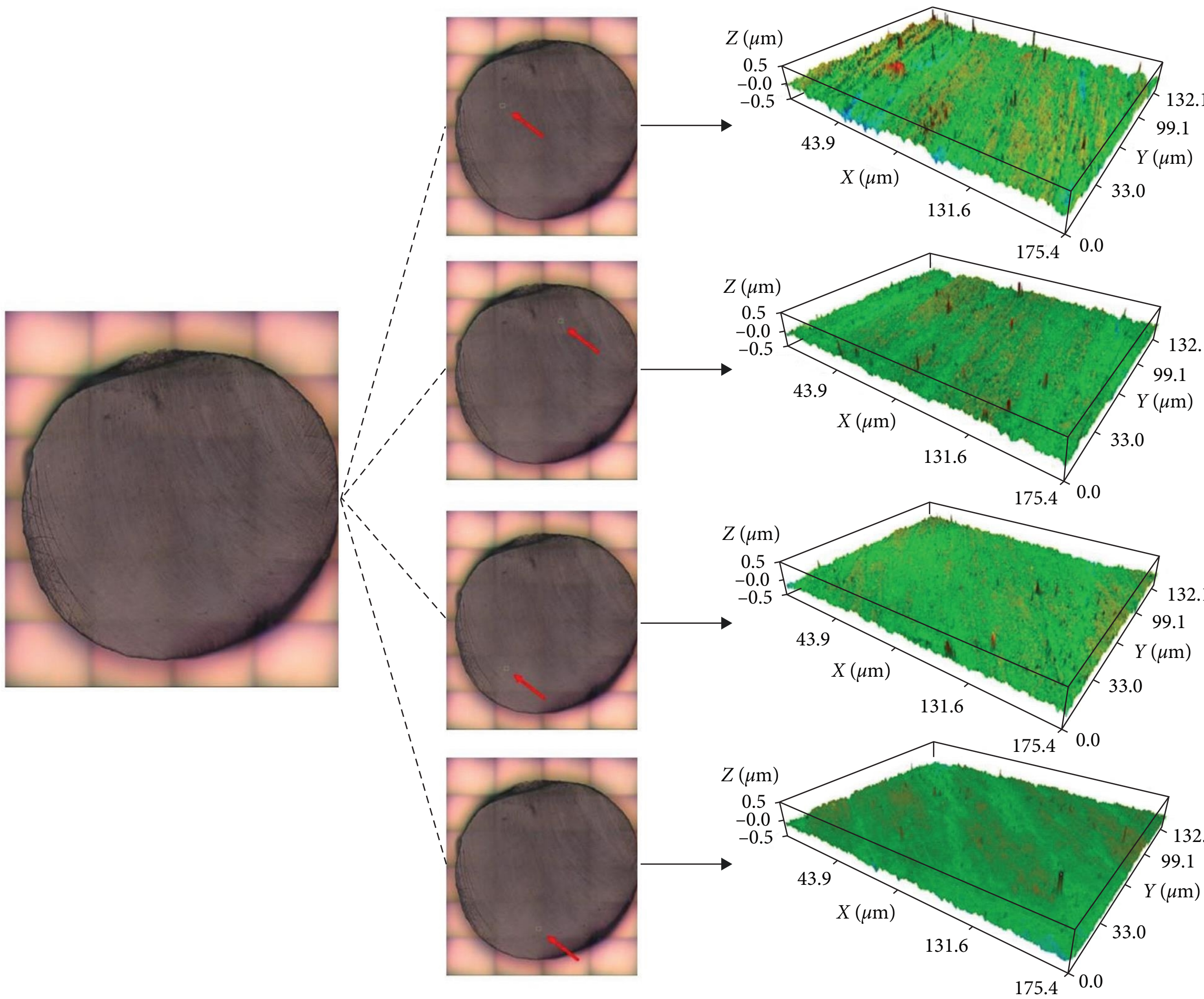


FIGURE 2: Schematic illustration of the acquisition of images from the 3D-optical profilometer. General view with magnification 10x in an area of $6.49 \times 7.26\,\text{mm}^2$ and visualization of a random choice of four sites on the sample surface with 100x objective in an area of $175.4 \times 132.1\,\mu\text{m}^2$.

TABLE 3: Mean (±s.d.) surface roughness (S_a in μm) of the tested composites with both finishing and polishing systems.

F/P system composite resin	E/P	SFD	ΔS_a (95% CI)	p^*
Zirconfill®	0.126 ± 0.020^a	0.209 ± 0.029^a	0.083 (0.055–0.111)	<0.001
Filtek™ Supreme XTE	0.082 ± 0.057^b	$0.187 \pm 0.060^{a,b}$	0.104 (0.045–0.164)	0.002
Brilliant EverGlow™	0.049 ± 0.019^b	0.086 ± 0.021^c	0.036 (0.017–0.056)	0.001
Ceram.X® Duo	0.077 ± 0.016^b	$0.121 \pm 0.033^{c,d}$	0.044 (0.017–0.070)	0.003
Harmonize™	0.070 ± 0.013^b	$0.144 \pm 0.040^{b,d}$	0.074 (0.046–0.103)	<0.001
p^*	<0.001	<0.001		

*One-way Welch ANOVA. Within columns, similar superscript letters indicate groups that do not present statistically significant differences ($p > 0.05$).

peaks, while they have approximately the same value for E/P. The exceptions are for the Ceram.X Duo material polished by SFD, with peaks larger than valleys, and Harmonize polished by E/P, where the valleys are much deeper than the height of the peaks. The analysis of these parameters (S_v, S_p) regarding the maximum height and depth of the topography is reinforced by the skewness as measured by the S_{sk} parameter. The data shows that, with SFD, except for Ceram.X Duo, the resulting surface is shifted toward negative values, indicating that peaks are predominant in the topography, despite the valleys being deeper than the height of the peaks. The action of the less aggressive E/P system is also shown by the opposite trend regarding the symmetry of the area occupied by peaks and valleys with a

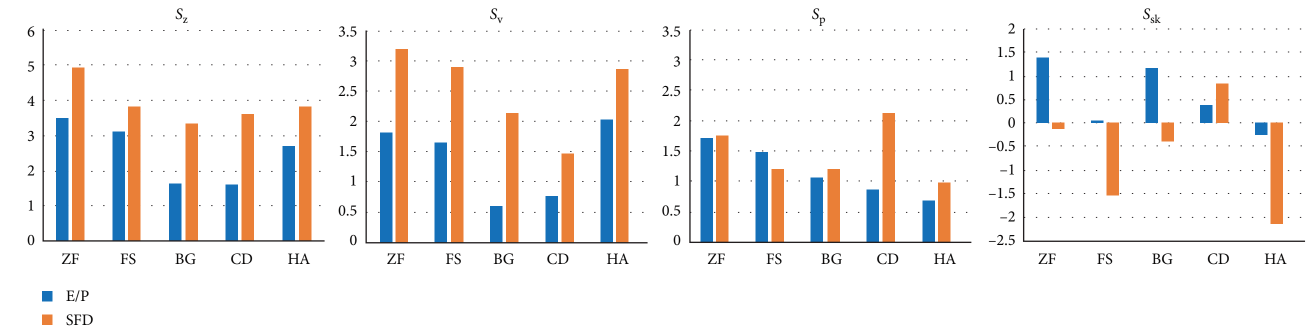
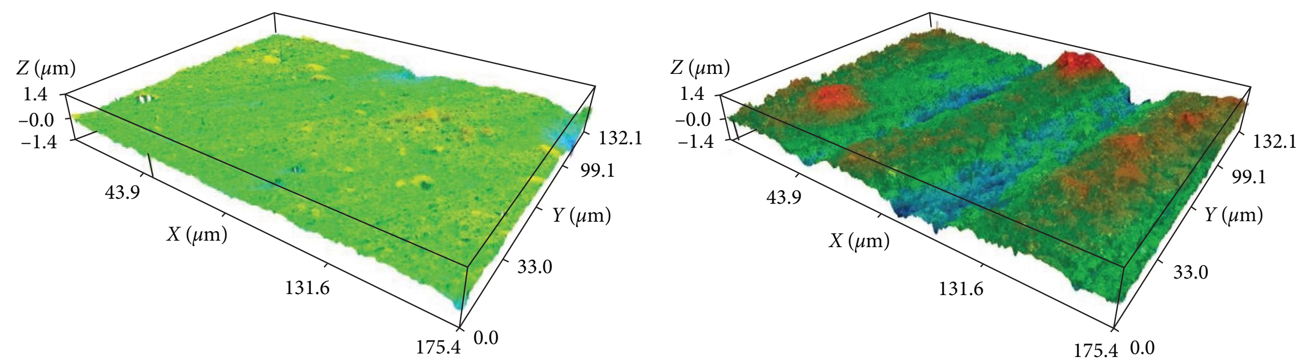
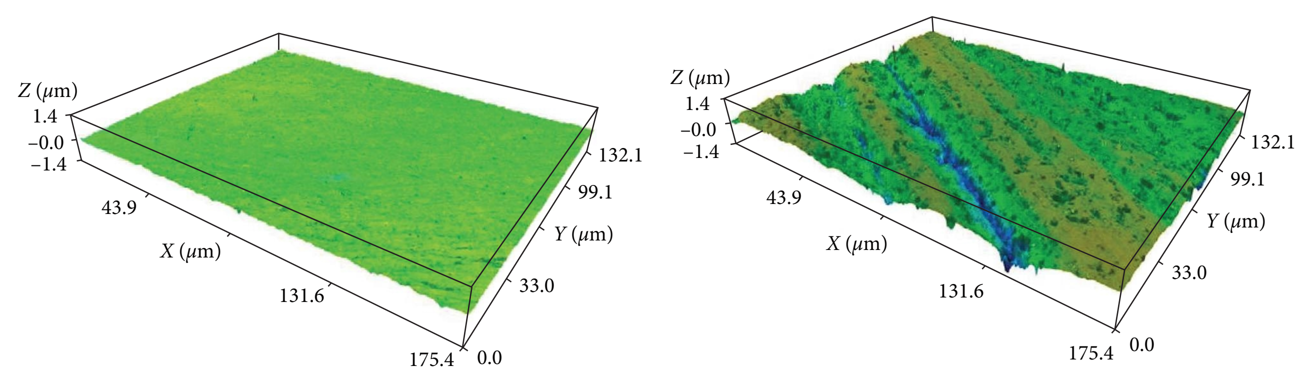


Figure 3: S_z, S_v, S_p, and S_{sk} roughness parameters variations for each resin composite according to the finishing and polishing system procedure.



(a) (b)

Figure 4: 3D image of a representative surface roughness of Zirconfill combined with (a) Enhance/PoGo system and (b) SwissFlex system.



(a) (b)

Figure 5: 3D image of a representative surface roughness of Filtek Supreme XTE combined with (a) Enhance/PoGo system and (b) SwissFlex system.

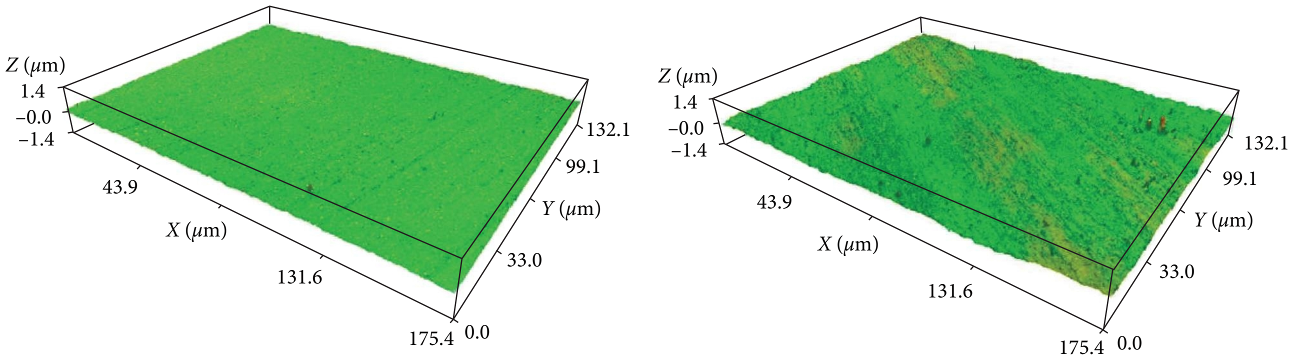
predominance toward valleys, as shown by the positive or very close to zero, values of S_{sk}, indicating a more uniform abrasive wear of the entire surface. It should, however, be noted that for very low S_a values, this indication of the asperity bias relatively to the mean plane loses some physical significance.

Representative 3D surface roughness images obtained through the optical profilometry for each resin composite and respective finishing and polishing systems can be observed in Figures 4–8.

Representative surface morphology images of each composite resin obtained by SEM can be observed in Figures 9–13.

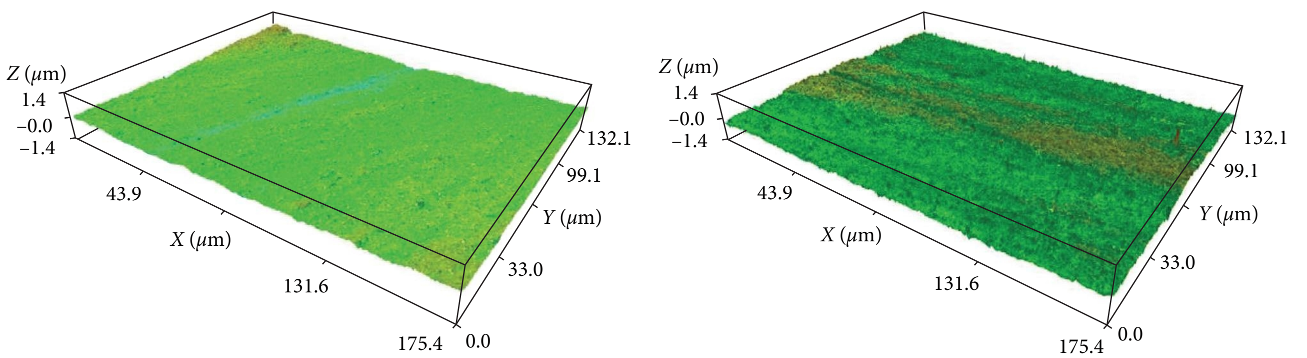
4. Discussion

The surface quality of resin composite restorations is one of the most important factors determining their esthetic and biological clinical success. Daily, the surfaces of resin composite restorations are directly exposed to degradation by biofilm attack, acid erosion, water sorption, occlusal and



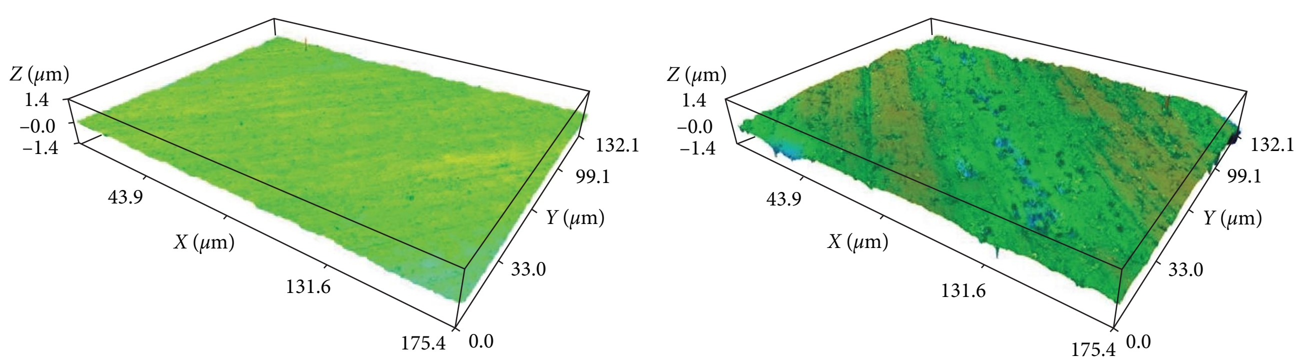
(a) (b)

Figure 6: 3D image of a representative surface roughness of Brilliant EverGlow combined with (a) Enhance/PoGo system and (b) SwissFlex system.



(a) (b)

Figure 7: 3D image of a representative surface roughness of Ceram.X Duo combined with (a) Enhance/PoGo system and (b) SwissFlex system.



(a) (b)

Figure 8: 3D image of a representative surface roughness of Harmonize combined with (a) Enhance/PoGo system and (b) SwissFlex system.

thermal stresses, and/or enzymatic degradation [5, 28]. Further, if restorations become inadequately polished, esthetics and longevity of composite resin restorations maybe committed, increasing the likelihood of occurring staining, plaque accumulation, gingival inflammation, and recurrent caries [3, 8, 10, 18, 27, 29].

This *in vitro* study aimed to investigate the surface roughness and morphology of five resin composites applied with two different finishing and polishing (F/P) systems. The null hypothesis was that (1) for each F/P system, there is no difference in surface roughness (S_a) between various resin composites, and (2) for each resin composite, there is no difference in S_a between different F/P systems. Both were rejected by the findings of this study as different F/P systems and resin composite types had an impact on S_a values. In terms of S_a, there was also a substantial interaction between

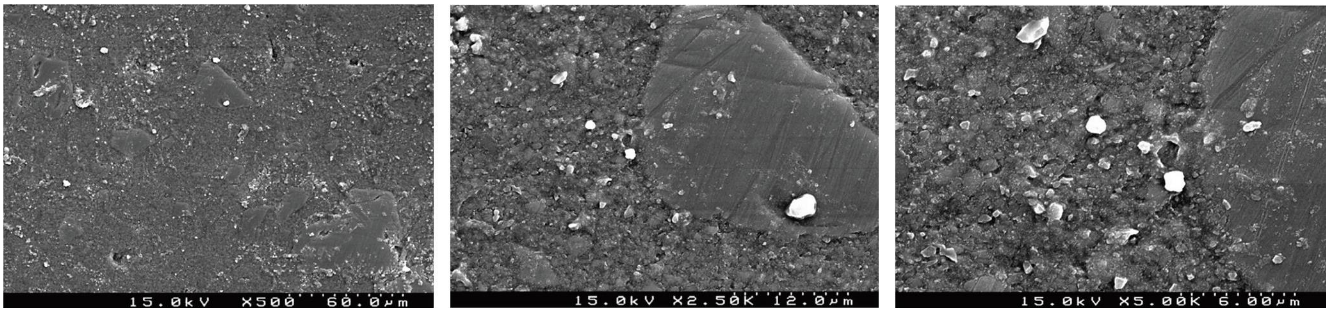


FIGURE 9: Scanning electron microscopy images of the surface of Zirconfill were obtained with three magnifications of 500x, 2,500x, and 5,000x. It can be observed a heterogeneous surface with irregularly shaped particles, some of them larger than 10 μm.

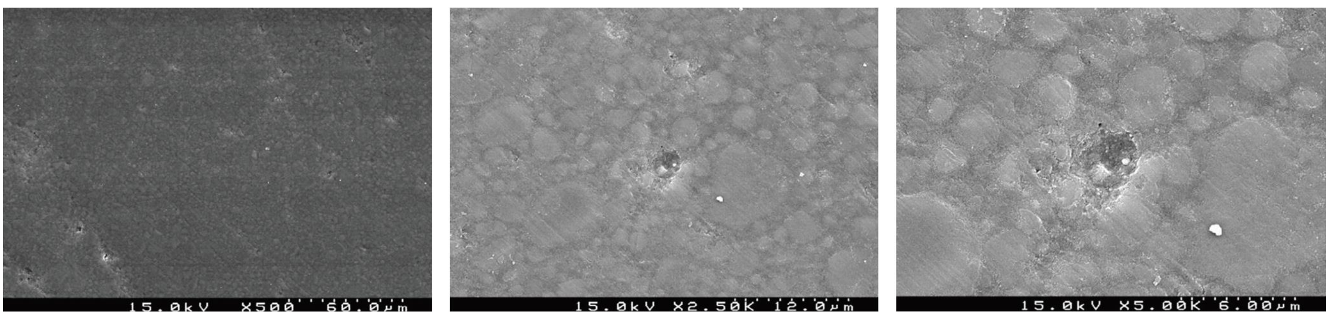


FIGURE 10: Scanning electron microscopy images of the surface of Filtek Supreme XTE were obtained with three magnifications of 500x, 2,500x, and 5,000x. It can be observed that nanofillers are spherical but organized in clusters of varied dimensions.

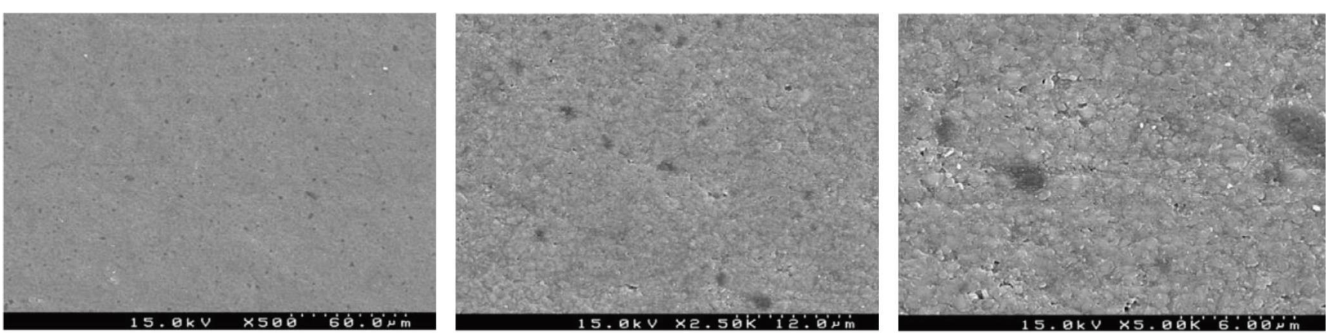


FIGURE 11: Scanning electron microscopy images of the surface of Brilliant EverGlow were obtained with three magnifications of 500x, 2,500x, and 5,000x. It can be observed a homogeneous surface where filler particles observed are rhomboid with a similar average size.

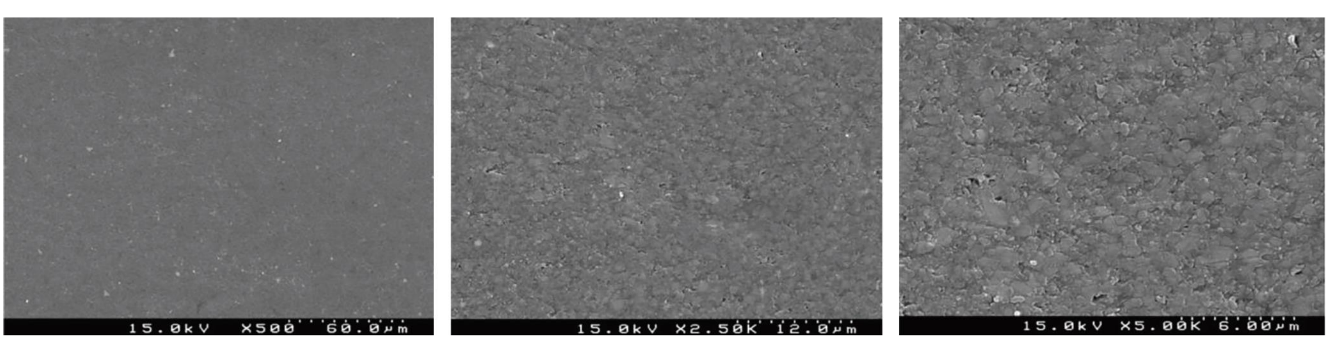


FIGURE 12: Scanning electron microscopy images of the surface of Ceram.X Duo were obtained with three magnifications of 500x, 2,500x, and 5,000x. It can observe a uniform surface with standardized, almost spherical particles.

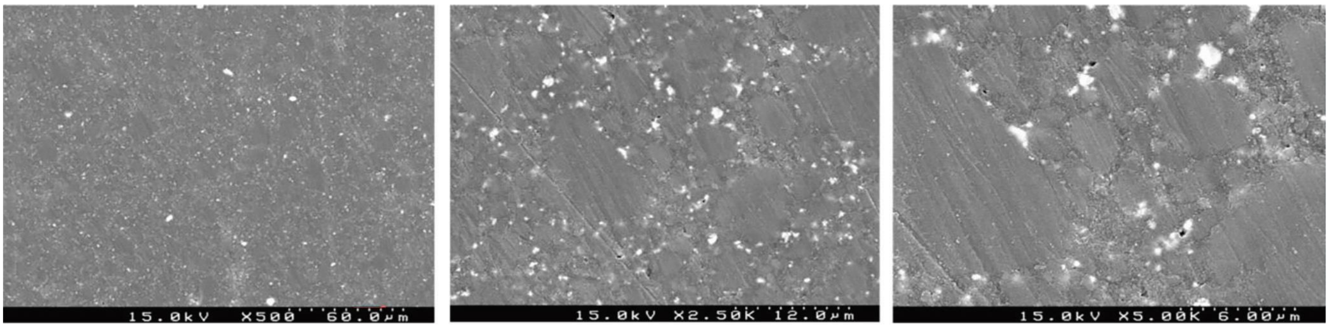


Figure 13: Scanning electron microscopy images of the surface of Harmonize were obtained with three magnifications of 500x, 2,500x, and 5,000x. It can observe a wide range of irregular filler-size particles.

the F/P technique and the resin composite type. FS was the composite resin most affected by the change of F/P method, whereas BG and CX presented the least difference in S_a roughness induced by both types of F/P systems.

While linear roughness parameters such as R_a/S_a have been widely used to characterize surfaces, it is also true that those alone are insufficient to fully understand most of the features present in the topography of a material. Additional parameters from the ISO 25178 standard, such as the maximum depth of the trenches or valleys (S_v) and the maximum height of the peaks (S_p) and their difference (S_z), further help clarifying it. Further information can be found in the data obtained from the optical profilometer, such as the skewness that represents the symmetry of the distribution of the volume of peaks and valleys (S_{sk}). Details such as the predominance of peaks or valleys or how sharp the transition is between these features can be very distinct for materials with the same R_a values. Parameters reflecting these features could not be found elsewhere and may be instrumental to help understand differences in the *in vitro* behavior of the polished materials. In the present study work, the S_z parameter showed the same trend as S_a for the surfaces of all materials finished with both the E/P and SFD polishing systems, indicating that the readings are reliable and reproduce as accurately as possible the resulting topographic changes. It further shows how strongly a surface can be modified locally and the potential detrimental impact it can have in the mechanical behavior of the material, since failure is more likely to occur due to larger defect-like areas represented by S_z and not to the average S_a values that present smaller magnitude values.

Zirconfil, Filtek Supreme, and Harmonize have the deeper valleys for both polishing systems when comparing with the maximum height of the peaks, most likely due to the pull out of the large particles present in these resin composites. The S_{sk} values reveal, however, the difference between these three composites with large particles embedded in the matrix. Their shift toward valleys (positive value) for Zirconfil for the E/P system indicates that wear occurs preferentially between the large filler particles, whereas for Filtek Supreme and Harmonize, these particles are much closer and may thus worn more homogeneously together with their respective polymeric matrixes.

These differences in surface texture can also be detected in the representative profilometric 3D images. From qualitative evaluation, it could be observed that for the E/P system roughness is tendentially sharper but shallower and that the SFD system produces a surface roughness with a volume of material that is biased toward peaks, probably due to the influence that filler particle plowing have on the resulting surface roughness. This is confirmed by the small values of S_{sk} for the Brilliant Everglow and Ceram.X Duo materials that do not show this exacerbated plowing effect.

The surface texture characteristic of resin composite restorative materials results from the different interactions of intrinsic and extrinsic factors. Intrinsic factors are related with matrix composition, type, shape, size, hardness, distribution of filler particles, degree of conversion, and interfacial silane bond quality between filler and matrix. Extrinsic factors are associated with F/P procedures and include the flexibility, shape, and chemical composition of the material, the grit size and hardness of abrasive particles, time and pressure applied, handpiece speed, access to the surface to be polished and method of application [3, 4, 13].

It is well documented that a polyester film matrix (polyethylene terephthalate) offers the smoother surface of a resin composite, leaving a resin-rich layer at the outermost surface. Nevertheless, when subjected to the oral environment, this layer wears off easily, due to its lower hardness, and the rough and unpolished inorganic filler becomes exposed, making the surface highly susceptible to discoloration. In addition, the surfaces must be abraded in order to remove excess, create the restoration morphology, and ensure occlusal compatibility with the antagonistic teeth. Therefore, finishing and polishing procedures are mandatory [2, 8, 30]. Simplified F/P systems were introduced in order to reduce clinical steps and minimize the risk of cross-infection and procedure time. In this study, a two-step polishing system combining the use of an aluminum oxide-impregnated silicon disc followed by diamond powder particles impregnated silicone disc (E/P) and a multiple-step polishing system using aluminum oxide abrasive discs (SFD) were examined. According to the results of the present study, only ZF produced a surface roughness larger than the 0.2 μm threshold for bacterial retention when polished with SFD. This reveals that for both F/P systems and resin composites, a good clinical performance regarding surface texture can be expected. Nevertheless, finishing with SF discs resulted in higher S_a values than finishing with E/P, regardless of the type of resin composite.

Resin matrix and inorganic filler diverge in hardness and do not wear out homogeneously; therefore, the abrasive particles of the polishing materials should comprise hardness superior to that of the inorganic particles of the resin composite to prevent extreme wear of the organic matrix. Also, in order to avoid scratches on the resin composite, the abrasive elements must be small or become smaller in multistep systems [15, 27, 30]. Aluminum oxide has a higher hardness than most filler particles in resin composites and can potentially induce smoother surfaces of resin composites as it promotes a more balanced wear among the organic matrix and inorganic filler components diminishing the probability of leaving filler particles protruding from the surface and, consequently, their dislodgement [4]. Both of the studied F/P systems have this abrasive in their composition. Nevertheless, the E/P system used the PoGo diamond powder-impregnated disc to end the polishing of the surface, which may have contributed to improving surface texture by fading scratches on resin composite surfaces.

Direct comparison of the results with other studies can be limited due to major or minor differences among the F/P protocols used. In different studies using the E/P system, a surface roughness lower than $0.2\,\mu$m was also found [31, 32]. Nevertheless, other studies reported higher roughness values, reaching a maximum of $0.84\,\mu$m in one study [17, 33, 34]. In addition to differences in applied rotational speed or pressure applied, reducing the application time in each step has been related to an increase in surface roughness when using the same system [4]. This aspect may explain the differences found between different studies. Other authors investigated the use of the Enhance and PoGo as isolated one-step systems, showing that surface roughness reached values only slightly superior to $0.2\,\mu$m [35–38], which can be clinically relevant as a simpler mode of use can be applied with this system. Additionally, different studies showed that small-sized diamond-containing polishing systems can create smoother surfaces in comparison with aluminum oxide due to their homogeneous and balanced capacity to polish both the filler particles and the resin matrix [30, 39, 40].

Concerning the SFD system used in this study, no comparison can be made with other studies as no publication was found addressing this issue using this system. Nevertheless, the use of aluminum oxide abrasive disks in a decrescent granulometry F/P protocol has been reported by several studies. Jaramillo-Cartagena et al. [4] reported, in a systematic review, that the Sof-Lex discs four-step system obtained an average surface roughness (R_a) of $0.091\,\mu$m after being applied in 154 samples compiled among five studies and that the Super-Snap Rainbow Technique Kit system exhibited an R_a average of 0.0799 reported in one study. Our results revealed surface roughness values slightly higher than those, but all managing to not exceed the limit of $0.2\,\mu$m except for ZF composite resin. It should be noted that suppressing steps or reducing the application time of each step can compromise the results, increasing the surface roughness of the resin composites. On the other hand, prolonged application of discs has been associated with heat-inducing surface microcracks generated by friction, especially if irrigation is not well addressed [8].

In line of the present findings, Daud et al. [14] compared surface roughness of Filtek™ Supreme XTE and Filtek™ Z250 when polished with Sof-Lex™ discs and Enhance® PoGo® system using a 3D-contact optical profilometry and results indicated that a smoother surface was accomplished when resin composites were polished with Enhance® and PoGo® system in comparison to the Sof-Lex™ system [14].

According to previous studies, the filler content and particle size of resin composite affects resin composite polishability, and a smoother surface is more noticeable in resin composites with higher inorganic content and smaller filler particle sizes. Using filler particles of a smaller size results in smaller filler plucking, reduced interparticle spacing, and better protection of the softer resin matrix. Also, higher filler content is expected to protect the resin matrix from excessive wear. However, when filler particles are much harder than the resin matrix, a more significant matrix wear during F/P procedures can be expected [1, 3, 8, 10, 14, 30, 41]. Among the resin composites studied, both BG and CD use nanosized, almost spherical fillers with a similar average size not containing zirconia. Both revealed a smoother surface in comparison to the other resin composites. The combination of the spherical shape, filler content, and a regular size distribution may have largely contributed to this result. Although FS uses nanosized spherical fillers, an inorganic component is organized in clusters of varied dimensions. Also, HA shows a wide range of irregular filler-size particles with aggregated clusters. These clusters are agglomerates of nanosized filler particles possibly linked weakly with the polymeric matrix, which can determine easier plucking of these cluster fillers after finishing inducing a rougher surface [41, 42]. On the other hand, different filler sizes and irregularly shaped fillers in resin composite can reduce the efficacy of surface finishing or polishing since they might receive more frictional forces during abrasion due to sharp edges that can be easily held by abrasives, facilitating their loss [43]. The resin composites containing zirconia as filler determined higher surface roughness values, which can be attributed to a higher hardness of this filler. ZF also presents diatomite, which is a silica with nanoscale pores that allow penetration of the monomers through them (information by manufacturer). It is possible that inhomogeneous polishing of these two components increases the roughness of this composite resin.

Unlike the 3D-optical microscopes used in other works, the S-neox uses visible light instead of a laser beam to produce the images, and thus, the lateral and vertical resolution depends on the magnification of the objective used. In order to produce a topographic image, the objective is moved vertically (Z-axis) at fixed intervals, the entire surface under analysis is observed, and an image of the spots under focus, as determined by the proprietary confocal technique, is acquired at each Z-level. The final 3D image is the sum of all the focused areas, each with X, Y, and Z information. This confocal technique coupled with the 100x objective ensures both a high lateral resolution, limited only by the Rayleigh criterion (ca. $0.15\,\mu$m for green light), and a vertical resolution below 2 nm. Besides a high resolution in the Z-axis, there is also, as a result, a 2D image of the surface where the entire area is fully focused irrespective of slopes or differences in height. These images complement the SEM pictures while yielding important quantitative topographic information.

It is recognized that the procedures of finishing and polishing of resin composite restorations ensure the longevity of the treatment and patient's oral health quality. However, there is no "gold standard" finishing and polishing material and/or technique patterned in the literature. In order to improve the comparison of data concerning the efficacy of finishing and polishing systems, it would be useful to standardize methodologies among studies. The proposed *in vitro* research presents some limitations. For instance, samples were evaluated on flat surfaces, when, in the oral cavity, restorations have various anatomic features. Furthermore, in a clinical situation, an increased incidence of irregularities may be found on restoration margins, which can impact more importantly in the survival rate of a restoration. Therefore, this topic should be addressed in the future through *in vivo* studies.

5. Conclusions

Within the limitations of this *in vitro* study, the following conclusions can be drawn:

(1) A significant interaction between the finishing and polishing technique and the resin composite type was found, in which Filtek™ Supreme XTE was the composite resin most affected by the change of finishing and polishing method, whereas Brilliant EverGlow™ and Ceram.X® Duo presented the least difference in surface roughness parameter.

(2) The Enhance® and PoGo® system was found to produce a smoother surface than the SwissFlex™ system.

(3) Within each finishing and polishing system studied, Brilliant EverGlow™ showed the lowest average surface roughness and Zirconfill® registered the highest.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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