Journal of
Composites Science

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Comparison of Polishing Systems on the Surface Roughness of Resin Based Composites Containing Different Monomers

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Abstract: Changes in the organic matrix of composite resins have been proposed to improve their surface properties. However, polishing systems may perform differently in different materials. This study compared the effect of polishing systems on the surface roughness of four composite resins containing different resin monomers: Admira Fusion (nanohybrid containing pure ormocer), Aura Bulkfill (nanohybrid containing Bis-GMA, UDMA), Charisma Diamond (nanohybrid containing TCD-DI-HEA) and Vittra APS (nanofilled containing UDMA). Cylinders (N = 120, $n = 10$) were prepared from each material and the top surface of each specimen was grounded using a diamond finishing bur. Baseline measurements of surface roughness (Ra) were recorded using a contact profilometer and the specimens of each composite were divided into three subgroups according to the polishing system: one-step, two-step, three-step. Ra measurements were recorded also after polishing. Data were analyzed using three-way ANOVA and Tukey's test ($p < 0.05$). The baseline roughness of all composites was significantly reduced after polishing ($p < 0.001$). The two-step polishing system provided the smoothest surface for Admira Fusion (0.0770 $\pm$ 0.0171) and Charisma (0.1091 $\pm$ 0.0090), whereas for Aura and Vittra no significantly differences were found for the three polishing systems tested. The surface smoothness seems to be more material dependent than step dependent, but all tested systems provided clinically acceptable results.

Keywords: composite resins; dental polishing; adhesive dentistry; operative dentistry

Citation: Augusto, M.G.; de Andrade, G.S.; Mathias-Santamaria, I.F.; Dal Piva, A.M.d.O.; Tribst, J.P.M. Comparison of Polishing Systems on the Surface Roughness of Resin Based Composites Containing Different Monomers. *J. Compos. Sci.* **2022**, *6*, 146. https://doi.org/10.3390/jcs6050146

Academic Editor: Thanasis Triantafillou

Received: 28 March 2022
Accepted: 12 May 2022
Published: 17 May 2022

1. Introduction

Composite resin restorations must present low surface roughness to maintain the periodontal health [1]. Usually, the polishing systems are composed of polishers containing abrasive grains with sequentially reduced sizes. However, there are systems that demand a single instrument. These one-step systems aim to reduce the clinical time, but they may not be as effective as the multistep polishing systems [2].

The surface roughness of a composite is related with the interaction of multiple factors, such as the filler (type, shape, size and distribution of the particles), resinous matrix, degree of conversion, and bond efficacy of the filler/matrix interface [3]. Despite the extensive literature related to the impact of different filler particles on the surface roughness, the impact of different resin matrices and polishing systems still needs to be clarified [4].

Currently, there are several types of resin-based composites available for dental application. Developed in 1956, Bis-GMA (bisphenol-A glycidyl methacrylate) was one the most promising monomers and has been the predominant used to produce resin composites [4,5]. This highly viscous monomer needs to be diluted in lower molecular weight dimethacrylate monomers to achieve an appropriate viscosity for clinical use [6]. However, the dilution of Bis-GMA increases the composite polymerization shrinkage and water sorption [4,7]. In general, the dentists were able to perform an adequate restoration with acceptable polishing characteristics (smoothness and brightness) using this kind of composite [5–7]. However, the Bis-GMA molecule contains bisphenol-A, which can bind to estrogen and androgen receptors, causing potential endocrine alterations [8]. For that reason, new restorative materials alternatives have emerged.

Aiming to reduce some limitations related to the Bis-GMA, new methacrylate monomers have been developed. UDMA (urethanedimethacrylate) presents similar molecular structure to Bis-GMA. However, the absence of phenolic rings results in a more flexible and biocompatible structure with lower viscosity, higher elastic modulus and hardness [9,10]. TCD-DI-HEA (tricyclodecane–urethane dimethacrylate) is derived from UDMA and according to the manufacturer, it combines low polimerization shrinkage with low viscosity. Although widely used in restorative dentistry, the residual methacrylate monomers can induce DNA damage [11]. Thus, the "pure ormocer" matrix may be an alternative to manufacture direct restorative materials. Ormocer (organically modified ceramic) is a molecule with a long inorganic silica chain and organic side chains [12]. Its larger size may reduce polymerization shrinkage, improve marginal adaptation, abrasion stability, and biocompatibility [13]. Although promising, the Ormocer molecule is more rigid than the derivatives of methacrylates, which can create more stress to the filler/organic matrix interface (promoting the detachment of some filler particles) [14]. Despite this fact, the evaluation of the most suitable polishing protocol according to different resin-based composites has not been extensively evaluated in literature yet.

Regardless of the used restorative material (which is often placed in the tooth cavity), it is mandatory an adequate finishing and polishing procedure to optimize the restoration surface quality and to minimize the dental biofilm formation [15]. Nowadays, a variety of polishing systems are available for resin-based composite materials, including multistep discs, fine and superfine diamond burs, abrasive discs, and diamond, silicon, or aluminum oxide-impregnated soft rubber cups. Some polishing systems are simpler which require less clinical steps, while others demand more time with a sequence of abrasive tools that should be rationally applied [15]. According to the literature, the finishing–polishing step involves a sequence of instruments, working to a progressively lower depth of cut [16–18]. However, there is no consensus in literature about the best method to improve the surface characteristics of microhybrid and nanofilled resin-based composites, or nether with regards to different composite matrixes, with studies showing significant difference between different polishing systems [15,18], restoration region [16] material type [17], and systems [15]. In addition, the degree of conversion difference between methacrylate and dimethacrylate resin-based materials could be based on their monomer combination type: the second has an addition-fragmentation monomer, which can promote the increase of degree of conversion better than methacrylate monomers, during polishing [19]. Nevertheless, discrepancies in the scientific literature on these issues associated with the contemporary available composite materials and polishing systems have revealed the demand for new studies on this topic [15–20].

Therefore, this study aimed to compare polishing systems with different number of clinical steps on the surface roughness of composite resins containing different monomers. The null hypotheses consisted that the polishing systems (1) would decrease the initial surface roughness, and (2) would promote similar surface roughness regardless the composite resin.

2. Materials and Methods

2.1. Sample Size Calculation

The sample size was defined based on previous results [14,21]. Using the G-Power software version 3.1 (Heinrich-Heine-Universität, Düsseldorf, Germany), it was possible to determine that with 90% power; alpha error of 0.05; standard deviation of 0.13; equivalence limit of 0.2; that 10 specimens would be required per group.

2.2. Specimens Preparation

One hundred and twenty cylindrical specimens were prepared using four composite resin (n = 30/per composite). The materials specifications are summarized in Table 1. For that, a single increment of each composite resin was inserted into a silicone matrix (6 mm in diameter; 2 mm in depth). Then, a polyester strip was placed over the composite resin and a microscope glass blade was pressed over it to create a flat surface. The glass blade was removed and the light curing procedure was carried out for 40 s using an LED device (Radii-Cal, SDI, Victoria, Australia), with an irradiance of 1000 mW/cm^2. To identify the bottom of the samples, a scratch was made using a scalpel blade. The specimens were stored in deionized water for 24 h at 37 °C to allow the completion of the polymerization reaction (Figure 1). The surfaces were analyzed under a stereomicroscope (Discovery V20, Carl Zeiss, Oberkochen, Germany) and those with imperfections were discarded.

Table 1. Specifications of the tested composite resins.

Material	Organic Matrix	Filler Composition	Filler Content (% *w*/*w*)	Type
Admira Fusion, VOCO GMBH, Cuxhaven, Germany	Ormocer-aromatic and aliphatic dimethacrylates, polysiloxane functionalized with methacrylate	Barium aluminum borosilicate glass, fumed silica (0.02–1 µm)	84	Nanohybrid
SDI, Bayswater, Australia	UDMA; BisGMA; BisEMA; TEGDMA.	Silica (20 nm) and silanized barium glass (400 nm)	81	Nanohybrid
Charisma Diamond, Heraeus Kulzer, Hanau, Germany	TCD-DI-HEA, UDMA	Barium aluminium fluoride glass (0.005–20 µm)	81	Nanohybrid
Vittra APS, FGM, Joinville, Brazil	UDMA, TEGDMA	Zirconia silicate (200 nm)	79	Nanofilled

To simulate similar surface finishing condition, a single operator used an extra-fine diamond bur (4138F, KG Sorensen, Cotia, SP, Brazil) mounted at slow-speed handpiece to finish the specimens for 30 s. A new diamond bur was used per specimen. Then, the specimens were washed with deionized water for 10 s and air dried (Figure 1).

2.3. Surface Roughness Analysis

To assess the effect of polishing protocol, the roughness was measured before and after polishing procedure. The baseline roughness (before polishing) values were measured by using a contact profilometer (MaxSurf XT 20; Mahr, Göttingen, Germany). The diamond stylus moved 4.2 mm along the specimen's surface with a speed of 0.1 mm/s (Figure 1). Three measurements were performed for each specimen, with 0.25 mm between them. The mean surface roughness (Ra) values were determined with a cut-off value of 0.25 mm [21].

After, the specimens were randomly divided in three subgroups (n = 10) according to the polishing system (Table 2).

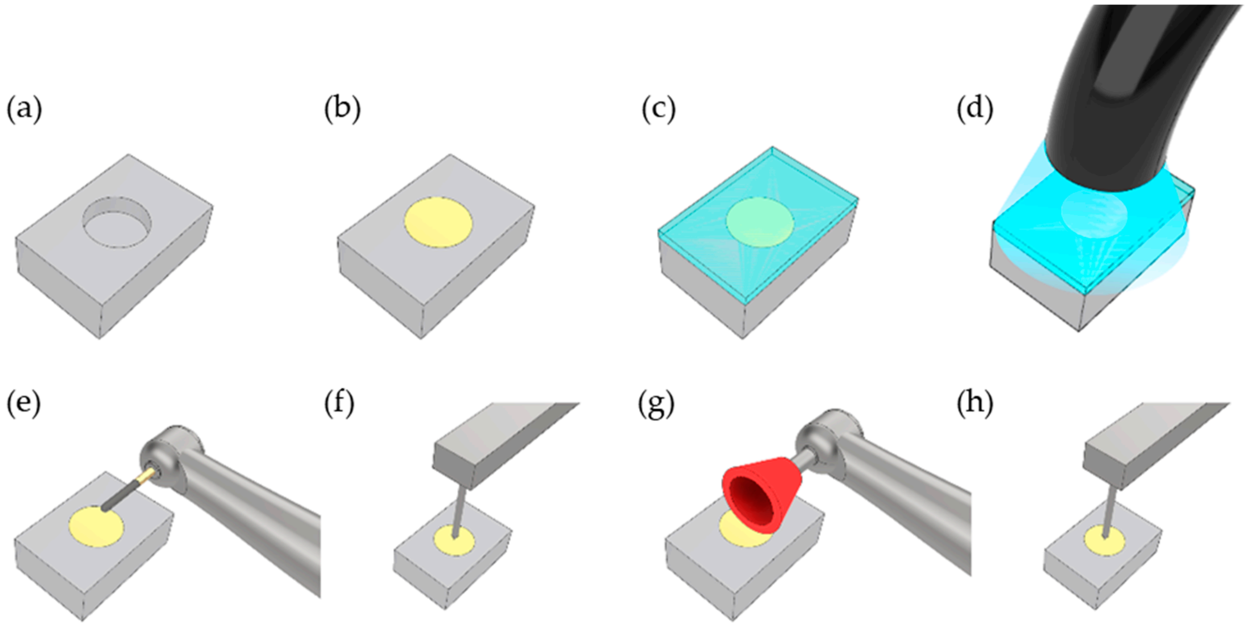

Figure 1. Specimen's preparation. (**a**) Silicone index (6 mm in diameter; 2 mm in depth); (**b**) composite insertion inside the index; (**c**) glass blade pressed to create a flat surface; (**d**) light curing procedure; (**e**) surface finishing simulation; (**f**) baseline roughness measurement; (**g**) polishing procedure; (**h**) roughness measurement after polishing.

Table 2. Specifications of the polishing systems tested.

Material	Abrasive/Description	Clinical Protocol
Dimanto, VOCO GMBH, Cuxhaven, Germany	Rubber disc impregnated with diamond particles	1 step
Diamond polishers for composite resins, Jota, Florianópolis, Brazil	Rubber discs impregnated with diamond particles with decreased size	2 step
Ultra-Gloss, American Burrs, Palhoça, Brazil	Rubber discs impregnated with silicon carbide particles with decreased size	3 step

2.4. Polishing Procedures

The polishers were mounted at a slow-speed handpiece and the specimens were polished during 30 s in each step. Specimens were thoroughly rinsed with distilled water and air-dried between each application step.

2.5. Data Analysis

The results indicated that the residuals were normally distributed and, by plotting against predicted values, the uniformity was checked. None of the analysis of variance (ANOVA) assumptions were violated. Thus, three-way ANOVA was performed for roughness data. Post-hoc pairwise comparisons were performed using the Tukey test, with a significance level of 5%. Minitab 17 Software (Minitab, State College, PA, USA) was used for the calculations.

2.6. Scanning Electron Microscopy

One representative specimen was randomly selected after the polishing and was further used for analysis using scanning electron microscopy (SEM; Inspect S50, FEI, Prague, Czech Republic). The specimen was sputter coated with gold for 180 s at 40 mA, creating a 30-nm-thick layer and examined under different standard SEM magnifications operated at 20 KV using secondary electron detection by a single operator.

3. Results

The roughness analysis showed significant difference for the composite resin ($p = 0.001$), polishing system ($p = 0.001$), and time (baseline × after polishing) ($p = 0.001$), as shown in Figure 2. Assuming a standardized threshold surface roughness for bacterial retention and comfort below which no further reduction in bacterial accumulation could be expected [15,20,21], all systems and materials seemed able to promote an adequate surface polishing with exception to Charisma Diamond with two and three step systems. Table 3 summarizes the mean and standard deviations for surface roughness.

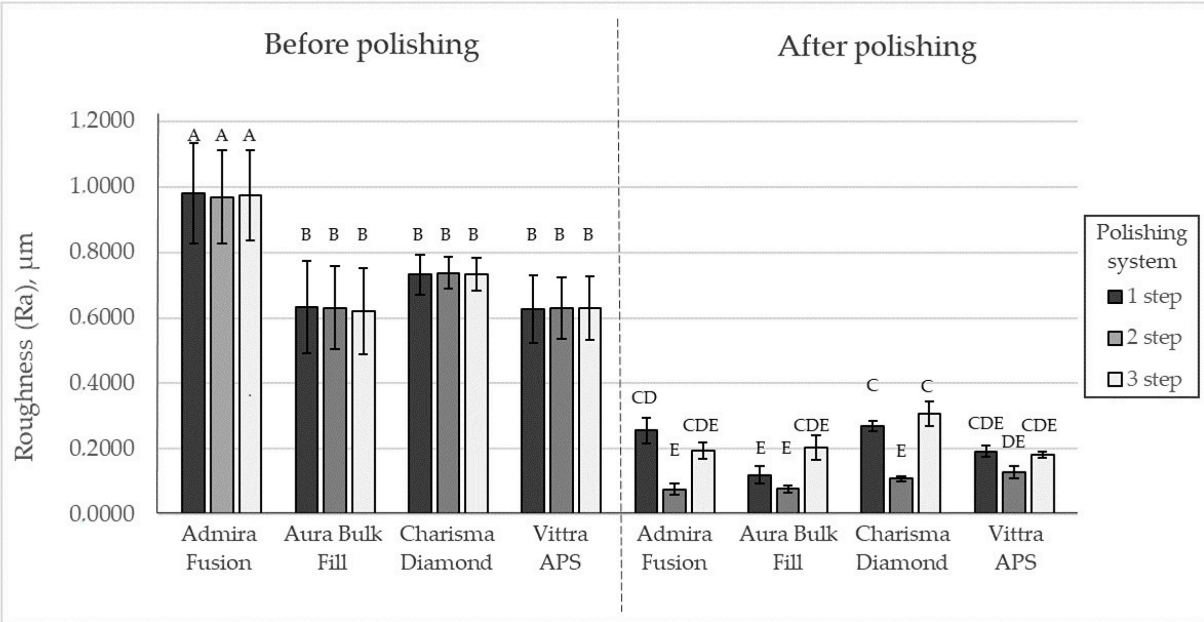

Figure 2. Mean surface roughness (Ra, µm), standard deviations and results of the Tukey test for each subgroup *. * Different letters indicate statistical differences between the subgroups.

Table 3. Mean ± standard deviation for surface roughness (Ra in µm) before and after polishing according to the composite resin and polishing system.

Material	Polishing System	Initial Surface Roughness	Surface Roughness after Polishing
Admira Fusion	Dimanto—1 step	0.9797 ± 0.1530	0.2561 ± 0.0393
	Diamond polishers for composite resins—2 step	0.9690 ± 0.1415	0.0770 ± 0.0171
	Ultra-Gloss—3 step	0.9740 ± 0.1377	0.1948 ± 0.0292
Aura BulkFill	Dimanto—1 step	0.6330 ± 0.1395	0.1210 ± 0.0260
	Diamond polishers for composite resins—2 step	0.6312 ± 0.1275	0.0775 ± 0.0103
	Ultra-Gloss—3 step	0.6203 ± 0.1309	0.2048 ± 0.0367
Charisma Diamond	Dimanto—1 step	0.7316 ± 0.0608	0.2693 ± 0.0162
	Diamond polishers for composite resins—2 step	0.7364 ± 0.0487	0.1091 ± 0.0090
	Ultra-Gloss—3 step	0.07334 ± 0.0449	0.3075 ± 0.0368
Vittra APS	Dimanto—1 step	0.6259 ± 0.1034	0.1931 ± 0.0170
	Diamond polishers for composite resins—2 step	0.6300 ± 0.0934	0.1294 ± 0.0185
	Ultra-Gloss—3 step	0.06296 ± 0.0958	0.1820 ± 0.0098

The baseline roughness of all composites was significantly reduced after polishing (p = 0.0001). When comparing the one-step and the two-step polishing system, the two-step provided the smoothest surface for Charisma and Admira Fusion, whereas for Aura and Vittra no significantly differences were found for the three polishing systems tested. Figure 3 shows the surface topography of Admira Fusion, with missing particles due to the polishing.

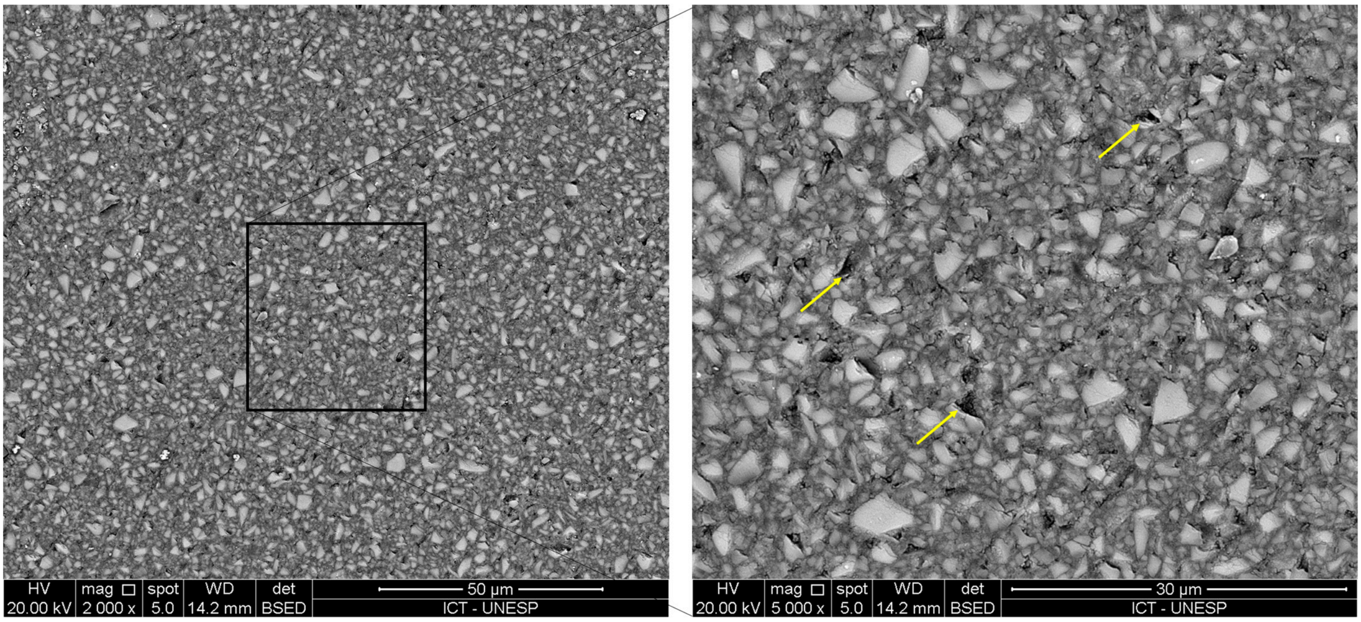

Figure 3. Representative Scanning Electron Microscopy (Admira Fusion) after polishing procedure at different magnifications (2000 and 5000×). The yellow arrows indicate the regions of surface defects caused by filler particles removal.

4. Discussion

This study aimed to compare polishing systems with different number of clinical steps on the surface roughness of composite resins containing different monomers. The results showed that the polishing systems decreased the initial surface roughness. However, different polishing systems and resin composites significantly influenced the surface roughness after polishing, thereby rejecting both null hypotheses.

Before polishing, Admira Fusion presented the roughest surface compared to the other resin composites that presented similar surface roughness. This may be possibly related to the lower silane coupling between the polymerizable organic group of the ormocer molecule and the silane molecule linked to the inorganic filler particles [21–23], which led to detachment of filler particle and creation of holes [23–25].

Finishing procedures remove gross excess of material, while polishing procedures remove small imperfections [24]. Polishability is an important characteristic of composite resins since a smooth surface gives the restoration better esthetics and comfort to the patient [3,25]. It was previously believed that roughness values greater than 0.2 µm increase biofilm accumulation and the risk of secondary caries [1,22]. However, this surface roughness threshold did not properly predict biofilm formation in nonclinical studies [26]. In addition, other clinical parameters influenced by surface roughness have been also described in the literature. The patient comfort can be associated with a smooth and well-polished restoration [22,27], in which the mean roughness values between 0.25 and 0.50 µm can be detected by the tongue. In this scenario, aiming for a reduced discomfort sensation, all evaluated materials would be acceptable regardless the polishing system. To provide comfort to the patient's tongue, the composites surface roughness similar to the intact enamel surface, which is about 0.64 µm, has also been reported [27]. Thus, according to the results of this in vitro study, the surface roughness of the composites would be clinically acceptable only after polishing.

The two-step polishing system provided a smoother surface than the one-step system for Admira Fusion and Charisma Diamond, whereas for Aura and Vittra no significantly differences were found between these polishing systems. The nanoparticles with size below 400 nm present in these composites ensure them a smoother surface than traditional nanohybrid materials as Admira Fusion (0.02–1 μm) and Charisma Diamond (0.005–20 μm) [28]. Thus, the absence of polishing with burs with larger abrasive grains might have left protruding the larger particles on the surface. The results of the present study highlights that the use of one-step polishing system may be suitable for nanofilled composites but not for nanohybrids.

The three-step polishing system demanded the longest clinical time among the evaluated systems (90 s). However, for Charisma Diamond the two-step polishing system provided better results in a reduced time (60 s). This finding supports the idea that the surface smoothness seems to be more material dependent than step dependent. For a polishing system to be effective, the abrasive particles must be relatively harder than the fillers. Otherwise, the polishing agent will only remove the soft resin matrix and leave the filler particles protruding from the surface [29]. The three-step polishing system evaluated is composed by rubber discs impregnated with silicon carbide particles (Mohs hardness = 9) with decreased size, whereas the two-step contains diamond particles (Mohs hardness = 10), which may be more efficient in grounding the larger particles of Charisma Diamond. Further studies should be performed to evaluate the effect of reduced clinical time for proximal cavities and restorations with indirect view [30–32].

It is important to mention that the evaluated materials present not only differences in the composite matrix but also in the reinforcement particles' type, size, hardness, and other factors that can possibly affect the surface polishing individually. Therefore, an association of factors present in the materials, with the common characteristic that all evaluated resin-based composites present similar clinical indication, should cause a difference in the results. For that reason, the comparison between them is possible and should be performed, since the same patient can be submitted to the restorative therapy with all of them. Since only few resin-based composites were evaluated, caution is needed in interpreting the results, and the conclusion of this study should be restricted only to the tested material. In addition, the methods are limited without considering the gloss and morphology surface characterization. Different finishing and polishing systems, materials combination, aging process, and operator errors can modify the present results and should be considered in further studies about the topic.

5. Conclusions

The surface smoothness of resin-based composites seems to be more material dependent than step dependent. However, all tested systems provided clinically acceptable roughness. The one-step polishing system may be suitable for nanofilled composites, but should not be the first choice for nanohybrid composites.

Author Contributions: Conceptualization, M.G.A. and G.S.d.A.; methodology, M.G.A. and G.S.d.A.; formal analysis, M.G.A., G.S.d.A. and J.P.M.T.; investigation, A M.G.A., G.S.d.A., I.F.M.-S., A.M.d.O.D.P. and J.P.M.T.; resources, M.G.A., G.S.d.A. and J.P.M.T.; data curation, M.G.A. and I.F.M.-S.; writing—original draft preparation, M.G.A. and G.S.d.A.; writing—review and editing, I.F.M.-S., A.M.d.O.D.P. and J.P.M.T.; project administration, M.G.A.; funding acquisition, M.G.A., G.S.d.A., A.M.d.O.D.P. and J.P.M.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data available on request.

Conflicts of Interest: The authors declare no conflict of interest.

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