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Effects of various finishing systems on the surface roughness and staining susceptibility of packable composite resins

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Abstract

Objectives: The purpose of the present study was to investigate the influence of various finishing systems on the surface roughness and staining of three packable resin composites and a conventional microhybrid one.

Methods: Three packable composites (Solitaire—Heraeus-Kulzer, ALERT—Jeneric-Pentron, SureFil—Dentsply) and a conventional microhybrid (Z250—3M-ESPE) were used. Composite specimens were prepared and polished with Poli I and Poli II aluminum oxide pastes, Ultralap diamond paste, Enhance finishing points, Politip rubber polishers, fine and extra fine diamond burs, and 30-blade tungsten carbide burs according to the manufacturers' instructions. The polished surfaces were evaluated with a profilometer, and then immersed in 2% methylene blue for 24 h. Afterwards, the specimens were prepared for the spectrophotometric analysis. Results were statistically analyzed by ANOVA and Tukey test.

Results: Significant differences were found for the surface roughness and staining recorded, with interaction among composite resins and the finishing systems used. No correlation was found between surface roughness and staining susceptibility ($p = 0.5657$).

Significance: For most of the polishing agents used, Z250 presented the smoothest surfaces and the least dye uptake. ALERT presented the roughest surfaces, and Solitaire, the highest dye concentration. The smoothest surfaces were not necessarily the most stain resistant. Staining is highly influenced by each composite monomer and filler composition.

Keywords: Resin composite; Surface roughness; Staining; Spectrophotometry

1. Introduction

Improvements in wear resistance, in conjunction with the total acid-etch technique allowed clinicians to place more reliable posterior resin-bonded restorations [1]. The introduction of packable composites provides a new option for posterior restorative procedures [2]. The heavier consistency of these materials is produced by fairly subtle modifications of the filler or resin component [3]. The mechanical and handling properties of dental composites depend to a large degree on the concentration and the particle size of the reinforcing filler [4–6].

Proper finishing and polishing are important steps that enhance both aesthetics and longevity of restored teeth [7,8]. Restoration finish, surface roughness and surface integrity, as well as the physicochemical properties of the material itself, can influence plaque retention, periodontal disease, recurrent decay and staining of the resin composite [9]. Various finishing and polishing techniques have been examined with different types of composite resins in an attempt to produce a smooth surface [10–12].

An unacceptable color match is a major reason for replacement of composite restorations [13]. Intrinsic factors due to changes in the filler, matrix or silane coating or extrinsic factors, such as adsorption or absorption of stains, may cause discoloration of aesthetic materials. The intrinsic color of aesthetic materials may change when the materials are aged under various physicochemical conditions, such as ultraviolet exposure, thermal changes and humidity [14]. The resin plays a major role in the color stability of resin composites. The resin's affinity for stains is modulated by its conversion rate [15] and its chemical characteristics, the water sorption rate being of particular importance [16–19]. Spectrophotometry and colorimetry, applied in both in vitro and in vivo environments, has made it possible to study the numerous parameters related to composite color stability [20–23].

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Table 1
Composites composition (bis-GMA: bisphenol A diglycidil ether dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; UDMA: urethane dimethacrylate; PCDMA: policarbonate dimethacrylate; bis-EMA(6): bisphenol A polyethylene glycol diether dimethacrylate)

Material	Particle size (μm)	Filler type	Filler content (%)	Resin	Batch number	Manufacturer
Solitaire, Shade A3	0.7–2.0	Silicon dioxide, Fluoride–barium–aluminum–borosilicate glass, Fluoride–aluminumsilicate glass	65 (weight) and 66 (volume)	bis-GMA and multifunctional methacrylic acid ester	038	Heraeus Kulzer GmbH, Wehrheim/TS, Germany
Alert, Shade A2	6 in diameter and 60–200 in length (glass fiber), 0.8 (irregular-shaped filler)	Microfilamentous glass fiber, Silicon dioxide, Barium–borosilicate glass, microfine silica	84 (weight) and 70 (volume)	bis-GMA, PCDMA, dimethacrylate groups	21894	Jeneric/Pentron, Wallingford, CT, USA
SureFil, Shade A	0.8–20	Fluoride–barium–aluminum–borosilicate glass	84 (weight) and 60 (volume)	Urethane modified bis-GMA	990915	Dentsply/Caulk, Milford, DE, USA
Filtek Z250, Shade A3	0.01–3.5	Zirconia, silica	60 (volume)	bis-GMA, UDMA and bis-EMA(6)	1370A3 OEW	3 M Dental Products, St. Paul, MN, USA

The aim of this study was to investigate the influence of various finishing systems on the surface roughness and staining of three packable and one conventional micro-hybrid resin composite.

2. Materials and methods

Three packable and a conventional micro-hybrid resin composites were used in this study: Solitaire, ALERT, Sure-Fil, and Z250, respectively. The polishing systems used were: aluminum oxide pastes—Poli I and Poli II (AP), diamond paste—Ultralap (DP), rubber polishers—Enhance (EN) and Politip (PO), diamond finishing burs—Fine and extra Fine (PD), and 30-blade tungsten carbide burs (CB). Composition, batch number and manufacturers of the composite resins and finishing and polishing systems are listed in Tables 1 and 2, respectively.

Thirty cylindrical specimens 3 mm thick and 5 mm in diameter of each resin composite were prepared in a poly-tetrafluorethylene split mold. The cavity was filled, using an amalgam plugger, and cured for 40 s with a visible light-curing unit Degulux (Degussa Hüls, Frankfurt, Germany). The specimens were stored in distilled water at 37 °C for 24 h and then randomly assigned to one of the six test groups, finished and polished by a single investigator according to the manufacturer's directions for use.

The pastes (AP and DP) and rubber polishers (EN and PO) were applied using a low-speed handpiece for 30 s, and felt wheels were used for the application of the pastes. High-speed 30-blade tungsten carbide burs and diamond finishing burs were applied for 15 s with water coolant.

After all specimens were polished, they were thoroughly rinsed with water and allowed to dry for 24 h before measurement of the average surface roughness (Ra). To measure the surface roughness of the specimens a profilometer (Surfcorder SE 1700—Kosaka Laboratory Ltda, Japan) was used. Three measurements in different directions were recorded for the five specimens on each group, the mean Ra value was determined for each specimen, and an overall Ra was determined for the total sample.

After the profilometric examination, the spectrophotometric analysis was carried out. The method used to quantify the dye uptake by the specimens was adapted from Douglas and Zakariasen [24], and Serra et al. [25]. Each specimen was immersed separately into 1 ml of 2% methylene blue solution at 37 °C. After 24 h, specimens were rinsed with distilled water for 30 s, air-dried, and ground into powder with a stainless steel mortar and pestle. The resulting powder was placed separately into new tubes, which were filled with 4 ml of absolute alcohol. After 24 h, the solutions were centrifuged at 3000 rpm for 3 min (IC-15AN, Tomy Seiko Co. LTD. Tokio, Japan) and the supernatant used to determine the absorbance in a spectrophotometer (DU 65, Beckman, Beckman Instruments Inc, Fullerton, CA, USA). Standard solutions of methylene blue

Table 2
Finishing and polishing agents composition

Material	Type	Abrasive	Batch number	Manufacturer
Poli I and Poli II (AP)	Paste	Aluminum oxide	00200	Kota, São Paulo, SP, Brazil
Ultralap (DP)	Paste	Ultrafine diamonds	9801	Moyco Union Broach, York, PA, USA
Enhance (EN)	Rubber point	Aluminum oxide, silanized pyrolytic silica	22450	Dentsply/Caulk, Milford, DE, USA
Politip (PO)	Rubber point	Silicon dioxide	29892001	Vivadent, Schaan, Liechtenstein
Diamond bur F and FF (DB)	Diamond bur	Ultrafine diamonds	990728	KG-Sorensen, Barueri, SP, Brazil
30-Blade multifluted carbide bur (CB)	Carbide bur	Tungsten carbides	A18150998	Beavers Dental, Morrisburg, Ontario, Canada

in 1 ml of absolute alcohol were prepared, containing from 0 to 4 μg of dye/ml. The absorbance of the standard solutions were determined at wave lengths ranging from 500 to 700 nm, and the best results were obtained at 668 nm. Prior to determining the absorbance at 668 nm of experimental solutions, the correlation coefficient (r) between dye concentration and absorbance of the standard solutions was calculated, an r value of 0.9997 was obtained. To estimate the dye concentration on the experimental samples, a linear regression was obtained. The regression equation was expressed as

$$y = 0.2716x - 0.0075$$

where y is the absorbance and x is the dye concentration. The dye uptake of each specimen was expressed as μg dye/ml, lower values indicating lower staining susceptibility.

For statistical analysis, two-way 4×6 analysis of variance was used, and to identify significant differences, a Tukey test at 0.05 level of significance was applied (SAS Institute Inc., Cary, NC, USA, 1999). A linear regression analysis was carried out to verify if staining was surface roughness dependant.

Two additional specimens of each group were prepared for the scanning electron microscope (DSM-940A—Zeiss, Munich, Germany). Specimens were sputter coated with gold to a thickness of approximately 50 Å in a vacuum evaporator (MED 010—Balzers Union, Balzers, Liechtenstein). Photomicrographs of a representative area of the surfaces were taken at $500\times$.

3. Results

The average surface roughness and the dye uptake for combinations of composite resins and polishing instruments are displayed in Tables 3 and 4, respectively.

The smoothest surfaces for Solitaire composite resin were recorded with AP, DP and PO. No statistically significant differences were observed among them ($p > 0.05$). For ALERT resin composite, the smoothest surfaces were evident with CB and DP ($p > 0.05$). SureFil recorded the smoothest surfaces when DP, AP and PO were used ($p > 0.05$). However, AP and PO presented results that were statistically similar to CB. Z250 composite presented the smoothest surfaces when DP was used. For most of the polishing agents used, Z250 presented the smoothest surfaces. The roughest surfaces for Solitaire, SureFil and Z250 were found when DB was used. For Solitaire, DB and EN produced equally rough surfaces. For Alert, PO and AP produced the roughest surfaces. Among the finishing and polishing agents studied, DP produced the smoothest surfaces on all the composite resins tested. But depending on the composite resin, other polishing agents attained very smooth surfaces as well.

Regarding the dye uptake by the composite resins, for most of the polishing agents used, ALERT and SureFil presented no statistical significant differences between each other ($p < 0.05$). All composite resins presented similar staining means when polished with the Enhance finishing system.

The least stained surfaces for Solitaire composite resin were found when the AP and DB were used. For the ALERT composite resin, the most stain resistant surfaces were attained with AP and PO, however, AP presented no statistical differences from DP and CB. For Z250 and SureFil, the most stain resistant surfaces were found when AP, DP and PO were used. Solitaire composite resin presented the most stained surfaces when PO was used. ALERT, presented the most stained surfaces when DB, and EN were applied. Z250 and SureFil presented the highest dye concentration means when DB, CB and EN were applied. All composite resins and polishing agents were tested in the linear regression analysis, which showed no correlation between surface roughness and staining susceptibility ($p = 0.56$).

4. Discussion

Proper finishing and polishing of posterior composites are important steps that enhance both aesthetics and longevity of restored teeth [7,8]. Surface roughness, associated with improper finishing and polishing can result in increased

Table 3
Surface roughness average (Ra) in μm (SD) produced by the finishing and polishing instruments (means followed by different letters (capital letter—column and lower case—line) differ among them by Tukey test ($p < 0.05$))

	Poli I e II (AP)	Ultralap (DP)	Diamond bur (DB)	Carbide bur (CB)	Politip (PO)	Enhance (EN)
Solitaire	0.112(0.003)Cc	0.118(0.013)Bc	0.742(0.171)Ba	0.423(0.036)Ab	0.157(0.044)BCc	0.741(0.136)Aa
ALERT	1.125(0.139)Aa	0.432(0.123)Ac	0.781(0.096)Bb	0.393(0.039)Ac	1.216(0.296)Aa	0.732(0.257)Ab
Z250	0.129(0.009)Ccd	0.084(0.009)Ce	1.078(0.189)Aa	0.180(0.017)Cc	0.120(0.007)Cd	0.648(0.104)Ab
SureFil	0.203(0.071)Bcd	0.147(0.044)Bd	0.931(0.100)ABa	0.261(0.019)Bc	0.187(0.022)Bcd	0.583(0.059)Ab

wear rates and plaque accumulation, which compromise the clinical performance of the restoration [9]. Composite surface roughness is basically dictated by the size, hardness and amount of filler, which influence the mechanical properties of the resin composites, and by the flexibility of the finishing material, the hardness of the abrasive, and the grit size [26,27].

Packable composite resins arose from the progressive development of composite restorative materials for posterior teeth [10]. The main differences between conventional and packable resin composites are due to modifications of the filler or resin component. The differences in surface topography between the composite resins tested in this study may be attributed to differences in their interparticle spacing and their filler particle size. Composite resin fillers appear to play an intrinsic role in how well a composite finishes [11,27–29]. The highest surface roughness averages were recorded for the larger particle composite resin ALERT, while the smoothest surfaces were recorded for Z250, followed by Solitaire and SureFil.

For a composite finishing system to be effective, the cutting particles (abrasive) must be relatively harder than the filler materials [30]. Otherwise, the polishing agent will only remove the soft resin matrix and leave the filler particles protruding from the surface, as seen on ALERT's surfaces polished with AP, DP and PO. ALERT composite resin is composed of relatively hard microfilamentous glass fibers, varying from 0.8 to 200 μm (Fig. 1). The lowest surface roughness for this composite was recorded when CB and DP were used.

For most of the polishing agents tested, the smoothest surfaces were recorded for the conventional microhybrid Z250. The best polishing was attained when DP was applied. The good results recorded for this composite can be explained by the filler particles size and arrangement, which vary from 0.01 to 3.5 μm.

Among the packable composites tested, Solitaire presented statistically lower means, similar to Z250, when AP and PO were used, because it is the packable composite that is composed of the smallest filler particle average size (0.6 μm). Despite SureFil's filler particles being relatively larger than Solitaire's, they presented similar surface roughness when polished with DP, DB, PO and EN, probably due to SureFil's particle arrangement, described by the manufacturer as an 'Interlocking Particle Technology'. SureFil presented statistically higher means when it was polished with AP. The resin phase suffered a preferential loss during polishing, leaving the largest particles protruding from the surface (Fig. 2).

As expected, the diamond finishing points and the Enhance finishing system produced rough surfaces on all composites [8,28,31]. When diamond points are applied, scratches can be seen on the surface topography of the composites, as shown on the SEM photograph (Fig. 3). The surfaces polished with the Enhance finishing points present some pitting, which may be to plucking of the filler particles during polishing (Fig. 4).

Color stability is critical to the long-term aesthetics of restorations and has been previously studied in vitro for a variety of restorative materials with different techniques [14–23]. Discoloration can be evaluated with various instruments. Since instrument measurements eliminate the subjective interpretation of visual-color comparison, spectrophotometers and colorimeters have been used to measure color changes in dental materials [32–35]. One of the most commonly used methods to assess composites' color changes is the reflectance spectrophotometry with the CIE (Comission Internationale de l'Eclairage) $L*a*b*$ color system [14,22,33,36–38]. Most in vitro studies have not quantified the staining of aesthetic restorative materials. The quantitative method of measuring staining, which has been used

Table 4
Means (SD) of dye concentration in μg/ml in composite samples subjected to various surface treatments (means followed by different letters (capital letter—column and lower case—line) differ among them by Tukey test ($p < 0.05$))

	Poli I e II (AP)	Ultralap (DP)	Diamond bur (DB)	Carbide bur (CB)	Politip (PO)	Enhance (EN)
Solitaire	0.060(0.006)Ad	0.148(0.022)Ab	0.063(0.011)Cd	0.107(0.048)Ac	0.273(0.023)Aa	0.087(0.013)Ac
ALERT	0.064(0.012)Abc	0.076(0.009)Bb	0.106(0.013)Aa	0.075(0.006)Bb	0.048(0.004)Bc	0.113(0.020)Aa
Z250	0.040(0.006)Bb	0.036(0.003)Cb	0.075(0.007)BCa	0.070(0.013)Ba	0.044(0.002)Bb	0.090(0.008)Aa
SureFil	0.049(0.007)ABb	0.060(0.010)Bb	0.085(0.016)ABa	0.081(0.010)ABa	0.055(0.007)Bb	0.098(0.015)Aa

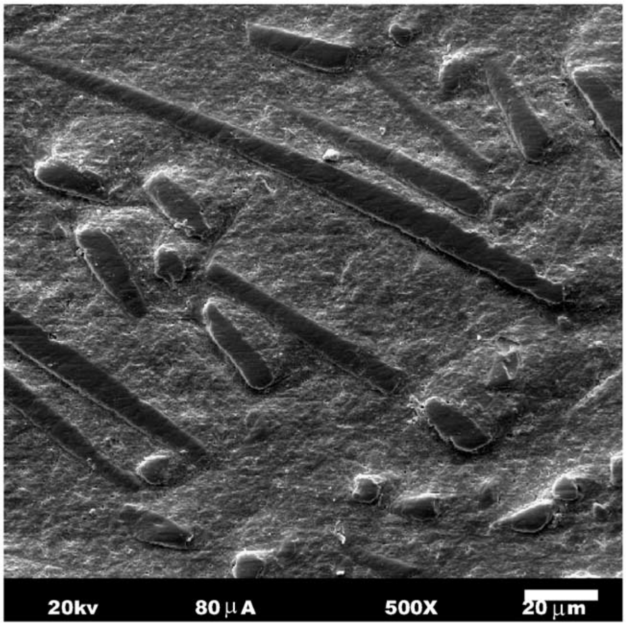

Fig. 1. SEM photograph of Alert composite resin and a diamond paste-produced surface.

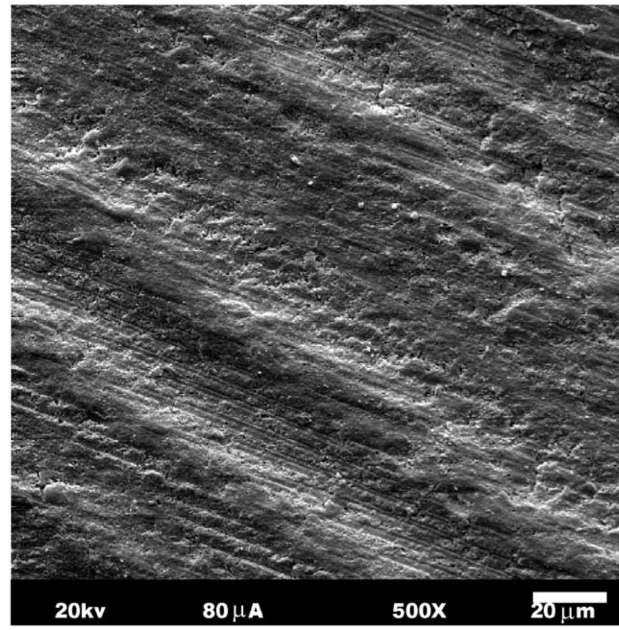

Fig. 3. SEM photograph of Solitaire composite resin and a diamond bur-produced surface.

for microleakage evaluation [24,39] and staining of glass-ionomer cements [40,41], was chosen because it allows the quantification of dye penetration into the material. In the present experiment, an absorbance spectrophotometer was used in order to quantify the dye uptake by the resin composites.

Discoloration of tooth-colored, resin-based materials may be caused by intrinsic and extrinsic factors. The intrinsic factors involve the discoloration of the resin material itself, such as the alteration of the resin matrix and of the interface of matrix and fillers. Every component may take part in this phenomenon. Extrinsic factors for discoloration include staining by adsorption or absorption of colorants as a result of contamination from exogenous sources. The staining of polymeric materials by colored solutions [17], coffee and tea [19], nicotine [42], and beverages [23] has been

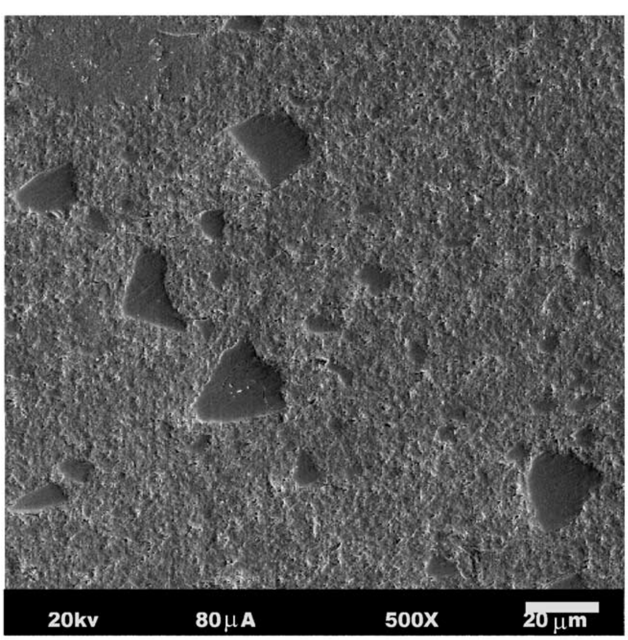

Fig. 2. SEM photograph of SureFil composite resin and an aluminum oxide paste-produced surface.

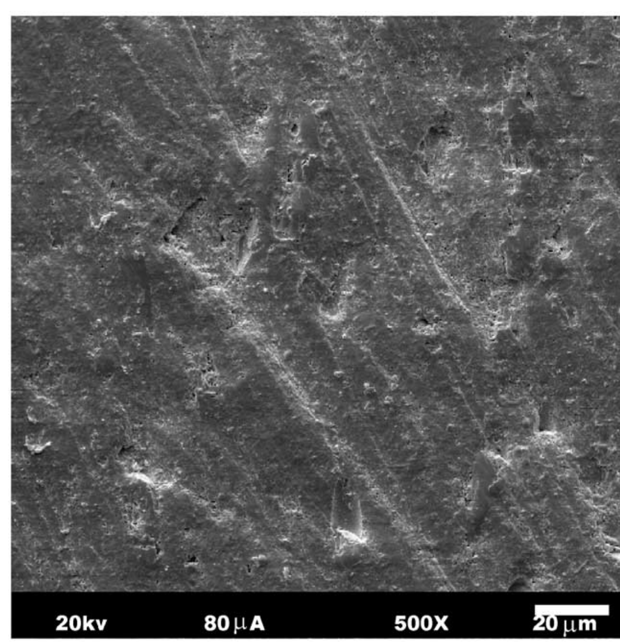

Fig. 4. SEM photograph of SureFil composite resin and an Enhance-produced surface.

reported. The extent of discoloration in the oral cavity may be associated with dietary habits.

Solitaire presented the highest dye concentration means for almost all polishing agents tested, probably due to intrinsic factors. These results corroborate with Iazetti et al. [14], where the unsatisfactory behavior is attributed to the porosity of the glass particles of the filler. Solitaire's staining susceptibility may also be attributed to the resin content, which contains a multifunctional methacrylate ester instead of traditional dimethacrylates. The cross-linked network produced from this monomer possibly includes many unreacted pendant methacrylates that serve as plasticizers [6]. It has been assumed that the plastification imparts to the polymers a more open structure, which facilitates the sorption of dyestuff [21].

A smooth surface was observed when Solitaire was polished with PO. However, it presented the highest dye concentration means. Apparently, the discoloration is not dependent on extrinsic factors such as surface roughness alone. A strained surface is more susceptible to staining. PO and EN were applied without water coolant, which might have strained the composite's surfaces. The strain increases the activity of the atoms on the surface and facilitates accumulation of the dye. The use of water coolant may prevent strain of the molecular arrangement of the resin matrix and inhibit detachment of the filler particles from the heat-softened resin [42].

Color stability is directly related to the resin phase of composites. Urethane dymethacrylate (UDMA) seems to be more stain resistant than bis-GMA [18]. Z250 presented low dye uptake means for most of the polishing agents tested. The resin system of Filtek Z250 consists of three major components: bis-GMA, UDMA and bis-EMA(6). The majority of TEGDMA, a somewhat hydrophilic monomer, has been replaced with a blend of UDMA and bis-EMA(6). According to the manufacturer, these resins impart a greater hydrophobicity to the composite resin. The low staining susceptibility of Z250 is probably related to a low water sorption rate due to the use of hydrophobic resins [16].

SureFil's performance is possibly related to its resin system and water sorption rate. It is composed of a urethane modified bis-GMA resin system. The manufacturer claims that the water sorption rate is 3.5 $\mu g/mm^3$. Despite its great surface roughness, ALERT recorded a staining susceptibility similar to SureFil, showing no statistical significant differences. Regarding the polishing systems, the highest dye uptake means for ALERT were recorded when EN and DB were used. For Z250 and SureFil, the highest means were found when EN, CB, and DB were applied. These results can be attributed to the irregularities left on the composites surfaces, like scratches and pits, which could favor the accumulation of dye extrinsically, as shown in Figs. 3 and 4.

In summary, the results of this in vitro surface roughness and staining test proved that the staining susceptibility of composites is not related to extrinsic factors such as surface roughness alone, but to intrinsic factors such as monomer and filler composition as well. A low staining susceptibility is generally related to a low water absorption rate or low resin content, and a satisfactory gloss after finishing. Each composite resin requires specific finishing and polishing devices, depending on the size, hardness and amount of filler of the composite used.

5. Conclusion

Surface roughness and staining susceptibility are directly influenced by each resin composite composition and polishing agent used. Results suggested that Z250 microhybrid composite is more easily polished to a smooth surface than packable composites, and presents low staining susceptibility. The highest surface roughness averages were recorded for the larger particle composite resin ALERT. Solitaire, which has porous filler and multifunctional monomers with different conversion rates, presented the highest dye concentration means.

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