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Original Article

Surface roughness evaluation of composite materials polished with one- or multi-step systems

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Abstract

Aim: As the spectrum of composite materials expands in the dental market, it's becoming more challenging to differentiate the structural properties and to find suitable finishing-polishing (f-p) materials. The main goal is to evaluate the impact of one and multi-step f-p systems on the surface roughness (SR) of current composite materials.
Methodology: In this study, nanohybrid bulk-fill (Filtek Bulk Fill Posterior [FBFP]), nanohybrid (Ceram.x One [CXO]), microhybrid (Filtek Z250 [FZ250]), and giomer bulk-fill (Beautifil Bulk Restorative [BBR]) composites were tested. After sample preparation and 24-h storage in 37 °C distilled water, each main group was assigned to one of two groups (n = 10): a one-step (One Gloss-PS) or a multi-step (Sof-Lex) f-p system. SR values (Ra, µm) were measured using a profilometer. Statistical analysis was done using Tukey HSD and ANOVA tests ($p < 0.05$).
Results: FZ250 showed the highest Ra values, regardless of the f-p system used. CXO showed statistically significantly lower SR scores than FZ250 ($p < 0.05$). There were no significant differences among the Ra values of the one- or multi-step f-p systems for FBFP and FZ250. Both the material and f-p systems had a significant effect on the Ra values separately.
Conclusion: FZ250 showed the highest Ra values, and composites polished with the multi-step f-p system exhibited slightly smoother surfaces than those polished with the one-step system.

Keywords: Surface roughness, nanohybrid composite, bulk-fill composite, microhybrid composite

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Introduction

The longevity of a dental restoration is linked to various factors, such as the operator's skills, the material's properties, and the patient's oral behavior (1). As parameters related to patients cannot be frequently managed by the clinician, it is beneficial to acknowledge the used materials' properties while performing the restoration steps. In recent years, the use of composite resin materials has increased due to the aesthetic demands of patients and improvements in material structures (2). When using tooth-colored restorative materials, it is crucial to provide esthetics as well as function. Smooth and shiny restoration surfaces are essential for the continued health of soft tissues and the restoration's marginal integrity, which can be obtained by sufficient contouring, finishing, and polishing procedures (3). Additionally, favorable light reflection, optimal esthetics, and protection against wear could also be provided by finishing-polishing (f-p) methods (4). Various materials and systems are used for these procedures, such as finishing burs or abrasive-impregnated polishing brushes (5, 6). The surface properties of a resin composite rely on its organic matrix composition, type, morphology, or size of inorganic particles, silane coupling agent usage, or monomer conversion rate (7). Regarding filler sizes, small fillers with higher loading minimize the spacing and thus form smaller gaps or voids following polishing procedures. The configuration of the structure also provides resistance to the resin matrix (8). In contrast, larger particles increase irregularity, which leads to rougher surfaces (1, 9). With improvements in technology, both the organic and inorganic parts of dental composites have changed, and the particles' sizes have altered. Composites with 0.4–1.0 µm particles are classified as "microhybrid composites" and are often used in anterior and posterior regions because of their combination of strength and polishability properties (10). The addition of nanotechnology to dentistry has led to modified formulations with the same particle size and prepolymerized fillers. So-called "nanocomposites" have been applied in the anterior region due to their superior polishability (10). Currently, ceramic particles are used in formulations to combine esthetics with high mechanical performance. Recently, bulk-fill composites have been used in increments of 4 mm and have more translucent matrices, different photo initiators, and smaller fillers (11). Another improvement is ion-releasing dental materials. One brand launched giomer bulk-fill composites with a high silicate glass ratio and ionic (S-PRG) fillers, which can release six ions: fluoride, sodium, borate, aluminum, silicate, and strontium. However, the releasing/recharging nature of the material may be related to nanoholes on the surface, either in acidic media or in artificial saliva (12). Conflicting results exist among studies that compared the surface roughness (SR) features of different types of composite materials (13, 14, 15). For this reason, more in vitro studies are needed to test new composites and polishing systems that can be used in clinics (16). Thus, the major goal of this study was to evaluate the effect of one- and multi-step f-p systems on the SR of currently used composite restorative materials. The null hypothesis was that there would be no significant difference between the SR values of the restorative materials and the f-p systems.

Materials and Methods

Nanohybrid bulk-fill, nanohybrid, microhybrid, and giomer bulk-fill composite materials were tested in this in vitro study. The materials and their contents are presented in Table 1. In total, 80 samples were prepared using a cylindrical Teflon mold (10 mm in diameter and 2 mm thick). The composite materials were placed in the molds, and their upper and lower surfaces were affixed with transparent matrix bands. A transparent matrix band and a 1-mm-thick glass microscope slide were placed over the samples, and constant finger pressure was applied to remove the excess material. All restorative materials were polymerized with a halogen light-curing unit (Optilux, CA, USA) for 40 s. Afterwards, the samples were removed from the mold and kept in an incubator for 24 hours in 37 °C distilled water. After the samples were removed from the incubator, they were divided into two subgroups according to the f-p system applied: either a one- or a multi-step f-p system. The systems used for the f-p procedures are described in Table 2.

Table 1. Types and compositions of the materials tested in the study

Material	Type	Composition	Manufacturer
Filtek Bulk Fill Posterior	Nanohybrid bulk fill composite	AUDMA, UDMA, 1,12-dodecane-DMA, non-agglomerated/ non-aggregated silica (20 nm), non-agglomerated/non-aggregated zirconia (4-11 nm), aggregated zirconia/silica cluster (20 nm), ytterbium trifluoride (agglomarate 100 nm) Filler Content: 76.5% (wt.), 58.4% (vol)	3M ESPE, USA
Ceram.x One	Nanohybrid (nanoceramic) composite	Methacrylate modified ceramic particles (1.1 – 1.5 µm) with polysiloxane backbone, barium alumino-borosilicate Filler content: up to 77% (wt.) / up to 55% (vol.)	Dentsply Sirona, USA
Filtek Z250	Microhybrid composite	Bis-GMA, Bis-EMA, UDMA, TEGDMA, zirconia, silica (0.01 - 3.5 µm, average:0.6 µm) Filler content: 78 wt%, 60 vol%	3M ESPE, USA
Beautifil-Bulk Restorative	Giomer bulk-fill composite	Fluoro-alumino-silicate glass, BisGMA, UDMA, TEGDMA, BisMPEP, Reaction initiator, others (0.01 -4 µm, average:0.8 µm).Filler content: 75% wt., 68.6% vol.)	Shofu, Japan

Abbreviations: AUDMA: aromatic urethane dimethacrylate, UDMA: urethane dimethacrylate, DMA: dimethacrylate, Bis-GMA: bisphenol A-glycidyl methacrylate, Bis-EMA: bisphenol A ethoxylated dimethacrylate, TEGDMA: triethylene glycol dimethacrylate, BisMPEP: bisphenol A polyethoxy methacrylate

Table 2. Finishing and polishing (f-p) systems tested in the study

Material	Composition	Manufacturer
One Gloss PS Set (One-step f-p system)	Synthetic rubber (polyvinyl siloxane), abrasive grain (aluminum oxide [Al_2O_3]), and silicon oxide (SiO_2)	Shofu, Japan
Sof-Lex (Multi-step f-p system)	XT Discs: polyester film, aluminum oxide grit, and binder Diamond PS: thermo plastic abrasive wheel, aluminum oxide, or diamond abrasive	3M ESPE, USA

In the one-step system, inverted cone shapes were selected and applied for 15 s, to each sample for finishing. According to the manufacturer's instructions, the material was applied for another 15 s with lighter pressure, in which the entire f-p procedure was completed in a single stage. The multi-step system (Sof-Lex System) was applied gradually according to the manufacturer's instructions. With the use of dark, light, and medium orange discs, respectively, each for 15 seconds, the finishing stage was completed. Then, using a prepolishing spiral and a diamond polishing spiral for 15 seconds each, the polishing stage was completed. F-p was performed by one experienced investigator to provide standardization without water. The surface was washed and dried before moving on to the next disc or spiral, and all the samples were stored for 24 h in a 37°C incubator with distilled water until SR measurements were taken. The roughness values for each sample were measured with three consecutive readings in the middle region of the specimens, and the mean Ra values (μm) were calculated. Before the measurements, each specimen's top surface was blotted dry using tissue paper and the contact guide of a surface profilometer (Surtronic 25; Taylor-Hobson, Leicester, UK) at the center of the specimen surface. The profilometer, calibrated against a standard after each measurement, was set to a cutoff value of 0.25 mm, a transverse length of 2 mm, and a stylus speed of 0.1 mm/s. The measurements were then averaged.

Statistical analysis

The statistical analysis was done using SPSS 23.0 (IBM Corp., Armonk, NY, USA) at a significance level of 0.05. The results were primarily analyzed using the Shapiro-Wilk test to determine the existence of a normal distribution. The results were analyzed by calculating the mean and standard deviation for each group. Statistical analyses for making comparisons between the test materials were conducted with Tukey's HSD and ANOVA tests.

Results

The mean SR values and standard deviations of the tested materials and f-p systems are shown in Table 3. According to the results, the microhybrid composite (Filtek Z250) showed the highest SR values, regardless of the f-p system used. There were no significant differences between the microhybrid and the giomer bulk-fill composite materials ($p > 0.05$); however, nanohybrid composites (Filtek Bulk Fill Posterior & Ceram.x One) showed statistically significantly lower SR scores than the microhybrid composite ($p < 0.05$). There were no statistically significant differences between the SR scores of the giomer bulk-fill samples and the other tested materials ($p > 0.05$).

Table 3. Mean and standard deviations of Ra values (μm) of all tested materials after one- or multi-step f/p systems

Material	F/P systems	
	One-step	Multi-step
Filtek Bulk Fill Posterior	$0{,}23 \pm 0{,}08^{A,\ c,d}$	$0{,}21 \pm 0{,}05^{A,\ d}$
Ceram.x One	$0{,}26 \pm 0{,}1^{A,\ e}$	$0{,}18 \pm 0{,}07^{A,\ d,f}$
Filtek Z250	$0{,}29 \pm 0{,}06^{B,\ e}$	$0{,}26 \pm 0{,}06^{B,c,\ e}$
Beautifil-Bulk Restorative	$0{,}25 \pm 0{,}07^{A,\ B,\ c}$	$0{,}21 \pm 0{,}04^{A,\ B,\ d}$

*Different uppercase letters show the significance between materials and different lowercase letters present the significance among f/p systems.

Table 4. Interaction of tested material and f/p systems with surface roughness scores					
	Sum of squares	Mean square	df	F	p
Material	0.046	0.015	3	3.31	0.025
F/P systems	0.036	0.036	1	7.73	0.007
Material * F/P systems	0.008	0.003	3	0.61	0.614

* The significance was set at $p < 0.05$.

Evaluating the f-p systems, there were no significant differences between the SR scores of the one- or multi-step f-p systems of the nanohybrid bulk-fill and the microhybrid composite. Also, there were significant differences detected among the f-p systems of the nanohybrid and giomer bulk-fill composites ($p < 0.05$). The results of the variance analysis, shown in Table 4, demonstrated that both the material and f-p systems had a significant effect on the SR values separately. However, the interaction of the materials and the f-p systems did not have a significant effect on the SR scores (p=0.614).

Discussion

The SR of composite materials may affect both the biological and esthetic parameters of the restorations and obviously decreases the longevity of the restorations. Irregular surfaces may lead to discoloration, biofilm accumulation, gloss reduction (13), gingival inflammation, increased wear, and secondary caries (13, 17). There are many factors that could influence the SR of composite materials, such as organic matrix composition, shape or type of inorganic fillers, monomer conversion degree, and properties of the silane coupling agent (18). Aside from intrinsic factors, the f-p systems applied at the end of restorative procedures are also crucial for final surface properties (4). The goal of this in vitro study was to compare the differences between restorative materials and to investigate the effect of f-p systems on SR. Because we detected significantly different SR scores among the materials and the f-p systems, the null hypotheses were rejected.

The surface properties of the restorative material may alter over time with a certain degree of abrasion, wear, or hydrolytic degradation (19). Therefore, to reveal the exact influence of the f-p systems commonly used in clinics, it would be advantageous to design a methodology with no environmental effects relevant to the oral cavity. With various types of composite materials, the referred methodology may also clarify the effects of the structural properties of the materials. Four of the different composites tested in the current study may be categorized by their inorganic fillers. The size, morphology, and composition of the organic fillers have a distinct effect on the f-p procedures and, finally, on the SR of the composite materials (17).

When evaluating the filler size, the occurrence of rougher surfaces is expected because of bigger particles, which may complicate f-p procedures (20). Also, when small fillers are plucked out of the surfaces during f-p systems, a smoother surface is obtained than materials with larger filler particles (17). Using small fillers provides less inter-particle spacing, which is beneficial for protecting the softer organic matrix from wear, abrasion during mastication, or tooth brushing (21). To provide continuation of the resin-filler integrity and obtain smoother surfaces, lower fillers vol.% were also influential. Lower filler-containing composite materials have been reported to show higher SR scores and wear occurrence (22). As composite resins commonly used on the market have 50–60 vol.% of inorganic fillers, the tested composites in the current study have 55 to 68.6 vol.% of fillers. However, composites with the highest vol.% fillers (giomer bulk-fill and microhybrid composites) showed rougher surfaces. This could be attributed to the relatively smaller particles of the tested nanohybrid composites of Filtek bulk fill (0.004–0.01 µm) and Ceram.x One (1.1–1.5 µm) among others.

Tamura et al. reported that the shapes of the inorganic fillers may affect the surface properties of the composite materials tested (23). This is because the corners and edges of irregularly shaped inorganic fillers may be removed and wear easily during toothbrushing or polishing with abrasives. Ceram.x One has spherical fillers, unlike the other composite materials tested. The lower SR values of Ceram.x One may be explained by not only its smaller particles but also its shape of the fillers. Furthermore, the composition of the fillers has previously been associated with the surface characteristics (17). Hard materials, such as silica, ceramics, or different types of glass, are generally used in inorganic filler composition (17). In particular, zirconia-based ceramic fillers have obviously higher hardness and wear resistance (24), so they have previously been assumed to provide lower SR results for composite materials in which they are used (17). However, composites containing zirconia fillers did not show consistent SR values (Filtek Z250 and Filtek Bulk Fill Posterior). Moreover, Filtek composites contain silane-treated inorganic fillers, which provide greater protection from abrasion or wear to the filler and matrix interface. However, consistent (significantly different) results were not obtained with these two composites in this study.

If the structures of fillers are compared, only giomer bulk-fill composite has a significant filler type, which is called S-PRG filler. It is essentially the glass ionomer that is milled and treated with silane and whose whole structure is finally incorporated into the resin matrix (25). These S-PRG fillers can release ions, and because of this, it has been claimed that the dissolution of these fillers creates surface irregularities and decreases microhardness (26). This might be the reason for the increase in SR changes. In the current study, no further imaging systems were used to investigate the structures of fillers. However, the higher SR values of the giomer bulk-fill composite (Beautifil-Bulk) may be explained by its fillers.

Rough, hard dental surfaces with Ra values higher than 0.2 µm increase microorganism retention, which can cause the formation of secondary caries, periodontal diseases, or discoloration of restorations (27). It was reported that streptococci adhered better to rougher surfaces because of their high surface energy relative to smoother surfaces (11). In the present study, except for the nanohybrid composite polished with the multi-step system, none of the groups exceeded the threshold, and there were significant differences between groups. It should also be noted that SR values higher than 0.3 µm could be felt with the tongue (28). Fortunately, none of the average SR scores of the groups were higher than 0.3 µm. However, the oral environment cannot be fully simulated in in vitro studies, and these studies need to be supported by clinical research. However, in vitro studies contribute to a better understanding of the structures of the tested materials and their responses to f-p systems.

When evaluating the results, there were numerically lower SR values detected in multi-step systems but no statistically significant differences. In giomer bulk-fill and nanohybrid composites, the multi-step f-p system significantly improved the surface smoothness. This may be related to the sequential shift from coarse to superfine-grained aluminum oxide-impregnated discs in the multi-step f-p system. This procedure gradually removes substance from the surface while reaching the deepest scratches (17). In the current study, a Sof-Lex system was used as the multi-step system, as it is reported to provide homogeneous abrasion of fillers and organic resin matrix, leading to similar surface properties, even for different composites (29). This finding was partially supported by the results of the present study in that only the microhybrid composite groups polished with the multi-step system showed significantly higher SR values than the other groups tested, which were polished with Sof-Lex. There was not a significant difference between the giomer bulk-fill and that of the microhybrid composite groups when polished with the multi-step system. Thus, the similar results could be attributed to the structural properties related to fillers and resin matrix properties, which were discussed above. This assumption could be supported by another finding of the study, namely that both the materials and f-p systems separately affected SR scores. In addition, the interactions between the materials and f-p systems did not significantly affect the SR values (Table 4). In a recent review, it was concluded that the effectiveness of the polishing system was material-dependent (30). Researchers have reiterated that care should be taken to prevent deep scratches and dislodged fillers on the surfaces of various microhybrid composites when using f-p systems that contain large particle sizes of aluminum oxide, such as Sof-Lex coarse discs (55 µm) and One Gloss PS (85 µm), as in the present study (31, 32). Due to the geometry of the Sof-Lex discs, they may be challenging to use, especially in the posterior region, although extra pressure may be applied to compensate for the limited movements. On the other hand, this disadvantage does not apply to One Gloss PS systems. In the end, the recommended approach is to use composite materials and f-p systems made by the same manufacturer (30). Thereby, f-p systems compatible with the hardness and size of the fillers of the composite materials could be intentionally manufactured.

Conclusions

As the present in vitro study was not designed to mimic the factors in the oral environment, no other parameters that could stimulate the surface properties, such as abrasive applications or chemical solutions, were included. In addition, structural differences in the f-p systems, such as the abrasive instruments' shapes, stiffness, flexibility, types of impregnated particles, amounts, and sizes, were not investigated. Within the limitations of the present study, the nanohybrid bulk-fill composite (Filtek Bulk fill Posterior) showed lower SR values, followed by the giomer bulk-fill (Beautifill-Bulk Restorative) and nanohybrid composites, including nanoceramics (Ceram.x One). The microhybrid composite showed the highest SR values of all. It was only the structural factors of the tested composite materials that may have exhibited differences after using one- or multi-step f-p systems. Further investigations focusing on the instrumental components of f-p systems should be designed.

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