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Surface Texture of Four Nanofilled and One Hybrid Composite After Finishing

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Clinical Relevance

Compared to a hybrid composite, with one exception, nanocomposites were significantly smoother after finishing with rigid rotary instruments and after using Sof-Lex discs. Using a 30 µm diamond caused detrimental surface alteration on nanofiller and hybrid composites.

SUMMARY

This study evaluated the surface geometry of four nanocomposites and 1 hybrid composite after finishing with rigid rotary instruments.

Four nanofilled composites (Premise, KerrHawe; Tetric EvoCeram, Ivoclar Vivadent; Filtek Supreme, 3M ESPE; Ceram X Duo, Dentsply) and one hybrid composite (Herculite XRV, KerrHawe) were used for the study. Sixty specimens were made of each product, 7x7 mm in size. Fifteen specimens of each composite were subjected to the following finishing procedures: a 30 µm diamond (FM1), a sequence of a 30 µm and a 20 µm diamond (FM 2) and a 30 µm diamond followed by a 12-fluted tungsten carbide finishing bur (FM 3). As a reference, 15 other specimens of each material were treated with Sof-Lex discs. Evaluation of the surfaces was done with laser-stylus profilometry. Roughness parameters were average roughness (Ra) and profile-length ratio (LR). Statistical analysis of the data was performed by two-way and one-way ANOVA and post-hoc tests by Scheffé. Additional qualitative assessment of the finished composite surfaces was done by scanning electron microscopy (SEM) at a tension of 25 kV.

The composite materials and the finishing methods had a significant effect on surface roughness (*p*<0.001 for Ra and LR). There were significant interactions between the materials and the finishing methods (*p*<0.001 for Ra and LR). Compared to Herculite XRV, three of the nanocomposites were significantly smoother after finishing, according to FM 1-3 and after application of the Sof-Lex discs. Ceram X Duo and Herculite XRV had similar surface roughness in terms of Ra and LR. Compared to a single 30 µm diamond and a sequence of two diamonds (FM 2), significantly lower roughness values on all composites were achieved by using a 30 µm diamond followed by a tungsten carbide instru-

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DOI: 10.2341/06-9

ment (*p*<0.001 for Ra and LR). Ra- and LR-values after FM 3 were similar or, in some cases, even lower than surface roughness measured after application of Sof-Lex discs. Evaluation by SEM revealed that the use of a 30 µm diamond caused detrimental surface alteration on all types of composites. A remarkable number of porosities were detected on 1 of the nanofilled composites.

INTRODUCTION

Hybrid composites are characterized by favorable mechanical and physical properties. Microfil materials show superior aesthetic quality, but due to compromising mechanical properties, their application is restricted to non stress-bearing areas. By utilizing methods of nanotechnology, a new class of dental composites has been developed in recent years. Conventional milling techniques have limitations with respect to reducing filler particle size below 0.1 µm.[1] Pyrogenic fillers with a particle size of about 40 nm are subject to aggregation phenomena; for this reason, the filler loading of Microfil composites is limited. Through nanotechnology, both nano-sized filler particles and high filler loading are achieved. Nanoparticle composites claim to combine the mechanical strength of hybrid composites and the superior aesthetic properties of Microfil materials.

The polish retention of a nanofilled composite was better than other products. Compressive and diametral strengths, fracture resistance and three-body wear of nanocomposites were equivalent to or superior compared to other composites.[1] Wear resistance of nanocomposites was found to be comparable or superior to Microfil and minifill composites.[2-3]

After placement of composite restorations, surface treatment is necessary. In the case of polyester film finishing, removal of the resin rich surface layer is recommended, because of compromising physical properties and increased discoloration.[4-5] The main indications for finishing are removal of excess material, shaping of the anatomical relief, occlusal adjustment and initial reduction of roughness in order to facilitate final polishing. In general, finishing is performed with rigid rotary instruments, such as diamonds with varying abrasive particle sizes and tungsten carbide finishing burs. In the case of smooth and convex surfaces, flexible discs can be used.

For traditional resin based composites, problems with respect to finishing and polishing arise from the fact that resin matrix and inorganic fillers have significant differences in hardness and do not abrade uniformly. Because of modified filler technology, nanocomposites might have different wear mechanisms when rotary instrumentation is applied, compared to hybrid and Microfil composites. For this reason, a re-evaluation of the effect of finishing procedures was deemed necessary.

This study investigated the effect of different finishing techniques with rigid rotary instruments and the effect of flexible discs on the surface geometry of four nanofilled composites and 1 conventional hybrid composite.

METHODS AND MATERIALS

Four nanofilled composites and 1 hybrid composite were used for this study (Table 1). Sixty specimens of each material were made using glass molds. Specimen size was 7x7 mm at a thickness of 4 mm. The specimens were cured with the polymerization unit Optilux 400 (VCL 401, Demetron, Danbury, CT, USA). Curing was performed from the bottom and top for 60 seconds each. The specimens were ground with sandpaper discs of 600 grit (Leco Corporation, St Joseph, MI, USA) for 30 seconds under water-cooling at 120 rpm (automatic polishing apparatus A 250, Jean Wirtz, Duesseldorf,

Table 1: *Details and Properties of the Composites Evaluated (based on information by manufacturers)*

Composite (Lot #)	Manufacturer	Filler Composition	Filler Content by Weight (%)	Filler Content by Volume (%)
Premise (406970)	KerrHawe, Bioggio, Switzerland	Silica nanoparticles (0.02 µm), Barium glass (0.4 µm), Prepolymerized filler (30-50 µm)	84	69
Tetric EvoCeram (F 38346)	Ivolclar Vivadent, Ellwangen, Germany	Barium glass, Ba-Al-Silicate glassfiller (0.4-0.7 µm), YbF_3, Mixed oxide, Prepolymers	83	68
Filtek Supreme (2 AB)	3M ESPE, Seefeld, Germany	Non-agglomerated nanosilica filler (20 nm), Agglomerated zirconia/silica nanocluster (0.6-1.4 µm)	78.5	59.5
Ceram X Duo (0407002141)	Dentsply, Konstanz, Germany	Ba-Al-Borosilicate glassfiller (1-1.5 µm), Silicon dioxide nanofiller (10 nm)	76	57
Herculite XRV (4-1092)	KerrHawe, Bioggio, Switzerland	Ba-Al-Silicate glassfiller (0.3-0.6 µm), SiO_2, ZnO, TiO_2	79	59

Germany). The specimen surfaces were assessed under a Stemi SV 6 (Zeiss, Goettingen, Germany) stereomicroscope. In case of irregularities, the specimens were discarded and new ones were used.

Three methods were used for finishing with rigid rotary instruments:

Table 2: *Details of the Rotary Instruments*

Type of Bur	Manufacturer	Order #	Particle Size/ Number of Blades
Finishing diamond	Brasseler, Savannah, GA, USA	806 314 290 514 014	24-40 µm
Finishing diamond	Brasseler, Savannah, GA, USA	806 314 290 504 014	15-30 µm
Tungsten carbide finishing bur	Brasseler, Savannah, GA, USA	500 314 290 072 014	12-fluted
Sof-Lex Discs	3M ESPE Dental Products, St Paul, MN, USA	1982 M 1982 F 1982 SF	29 µm 14 µm 5 µm

- FM 1: solely with a 30 µm diamond (n=15 per composite)
- FM 2: with a sequence of a 30 µm and 20 µm diamond (n=15 per composite)
- FM 3: with a 30 µm diamond followed by a 12-fluted tungsten carbide bur (n=15 per composite)

Additionally, 15 more specimens from each material were treated with flexible Sof-Lex discs from medium to extra-fine (SL). Details of the instruments are provided in Table 2. Application time was limited to 30 seconds for each instrument. The samples from each material and each finishing method were distributed equally between 2 operators who were performing manual rotary instrumentation. Selection of the type of composite and finishing method followed a randomized protocol.

The diamonds and tungsten carbide burs were mounted in a new red-ring handpiece 24 LN (Intramatic Lux 2, KaVo, Biberach, Germany) and used at 40,000 rpm under 3-way water cooling. After application on five specimens, a new instrument was used.

Sof-Lex discs were applied in a blue-ring handpiece 20 LH (Intramatic Lux 3, KaVo) at 3000 rpm under two-way water-cooling. Each disc was only used for a single specimen.

After finishing, the composite surfaces were assessed for roughness quantitatively and qualitatively. Quantitative evaluation was done with optical profilometry. The surfaces were scanned by a Focodyn laser stylus (Rodenstock, Munich, Germany). An S8P (Mahr, Goettingen, Germany) was used for monitoring the measuring conditions and processing the profile data. Each surface was scanned by 9 parallel tracings, which were generated automatically. The distance between two tracings (Dy) was 0.219 mm. The profilometric settings were:

LT (Transverse length) = 1.75 mm

LM (Sampling length) = 1.25 mm

VB (Vertical Band Width) = ± 62.5 µm

λc (cut-off) = 0.25 mm (Gauss profile-filter)

The size of the surface area per specimen to be evaluated profilometrically was 1.25 x 1.75 mm.

For characterization of surface roughness, average roughness (Ra, as per ISO 4287[6]) and profile-length ratio (LR, as per DIN 4762[7]) were calculated. LR is dimensionless, representing the length of a profile tracing drawn out to a straight line (true profile length) in relation to the sampling length. An ideally smooth surface yields LR=1.

Ra and LR data were distributed normally and analyzed by two-way and one-way ANOVA and post-hoc tests by Scheffé. Statistical analysis was carried out using SPSS for Windows (version 11.5).

Eight specimens from each composite were selected for evaluation by scanning electron microscopy (SEM). Two samples each were taken from the three finishing groups and the disc group. The specimens were gold-coated with the sputtering device SCD 040 (Bal Tec, Balzers, Liechtenstein). Qualitative examination was performed using the PSEM 500 (Philips, Eindhoven, Netherlands) at a working tension of 25 kV.

From each surface, a photomicrograph was taken at an original magnification 80x. Photoprints 16x12 cm in size were made from each micrograph and used for further evaluation. After subdividing each photoprint into 48 squares, each square was assessed separately with respect to surface roughness in four possible gradings:

- Smooth, homogeneous surface
- Minor roughness
- Severe roughness
- Detrimental surface area

With respect to the type of composite and finishing method used, qualitative evaluation was blinded.

RESULTS

Quantitative Evaluation

The different composite materials had a significant effect on surface roughness with respect to Ra and LR

(p<0.001). The finishing methods had a significant effect on Ra and LR (p<0.001). There were interactions between the composites and finishing methods in terms of Ra and LR (p<0.001).

After finishing according to FM 1-3 and after use of Sof-Lex discs, Premise specimens had the lowest average roughness (Ra=0.993 µm; Figure 1A) and profile-length ratio (LR=1.340, Figure 1B). Ra-values of Ceram X Duo and Herculite XRV specimens were significantly greater (p<0.001; Table 3A), and LR values of all other composites were significantly greater compared to Premise (p≤0.039; Table 3B).

The greatest roughness was measured on Ceram X Duo specimens (Ra=1.087 µm, LR=1.528) and Herculite XRV surfaces (Ra=1.101 µm, LR=1.499). The differences to the other composites were significant (p≤0.001 for Ra and p<0.001 for LR).

Roughness was greatest on all composites after using the 30 µm diamond. There were only minor differences between composites, and Ra-values varied between 1.92 µm for Ceram X Duo and 2.14 µm for Herculite XRV (Figure 2A); LR-values were between 1.47 (Premise) and 1.66 (Ceram X Duo, Figure 2B).

After finishing with a sequence of two diamonds, there was a significant reduction in average roughness on all composites compared to FM 1 (p<0.001). The specimens yielded Ra-values that ranged from 0.86 µm (Tetric EvoCeram) to 1.025 µm (Ceram X Duo). In terms of LR, there was a significant reduction in roughness only for Herculite XRV, Ceram X Duo and Tetric Evoceram (p≤0.018). The Premise (p=0.56) and Filtek Supreme (p=0.27) surfaces were similar compared to FM 1.

The use of a 30 µm diamond and tungsten carbide bur (FM 3) achieved a further significant reduction in roughness compared to FM 2 (p<0.001 for Ra and LR). After FM 3, roughness was lowest on Premise specimens (Ra=0.42 µm and LR=1.177) and greatest on Ceram X Duo specimens (Ra=0.64 µm and LR=1.436).

Treatment of the composite specimens with Sof-Lex discs achieved a surface quality similar to the surface condition after FM 3. Roughness varied between Ra=0.41 µm and LR=1.208 for Premise and Ra=0.76 µm and LR=1.452 for Ceram X Duo. The differences in roughness after using FM 3 and Sof-Lex discs were only minor and of no significance in terms of Ra and LR (p>0.05). Compared to SL, only Ceram X Duo specimens had significantly lower Ra-values after FM 3 (p=0.007).

Figure 1: *Overall roughness of four nanoparticle and one hybrid composite surfaces (mean value with 95% confidence interval) after finishing with rigid rotary instruments and polishing with flexible discs.*

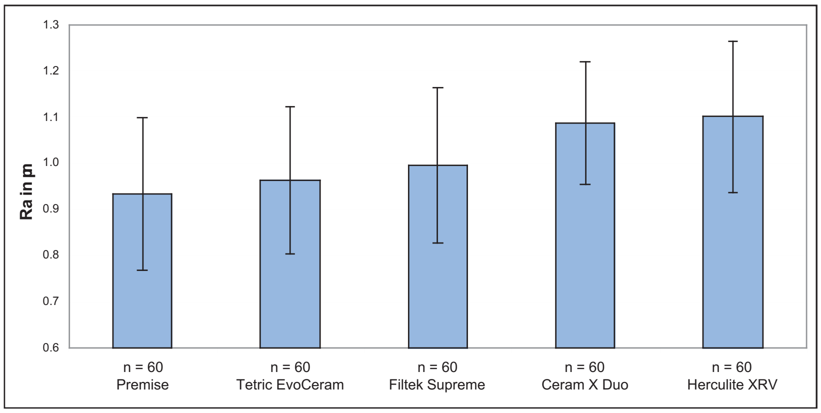

Figure 1A: *Average roughness (Ra).*

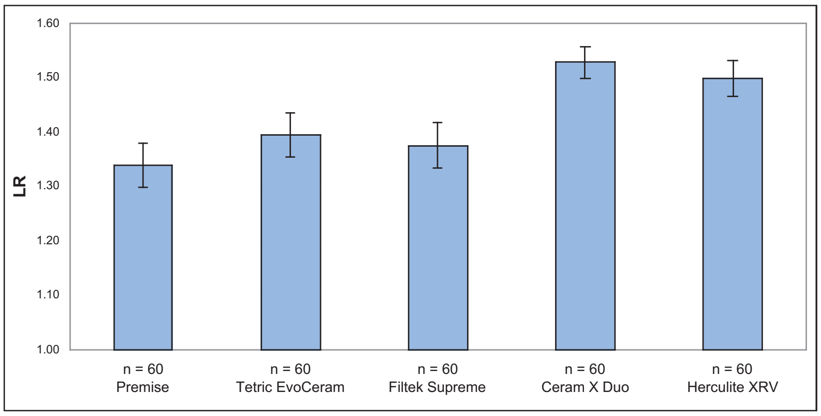

Figure 1B: *Profile length ratio (LR).*

Figure 2: *Roughness of four nanoparticle and one hybrid composite surface after finishing with 3 different methods and after use of Sof-Lex discs; each column represents a mean value ± SD of n=15 specimens (TCFI–tungsten carbide finishing instrument).*

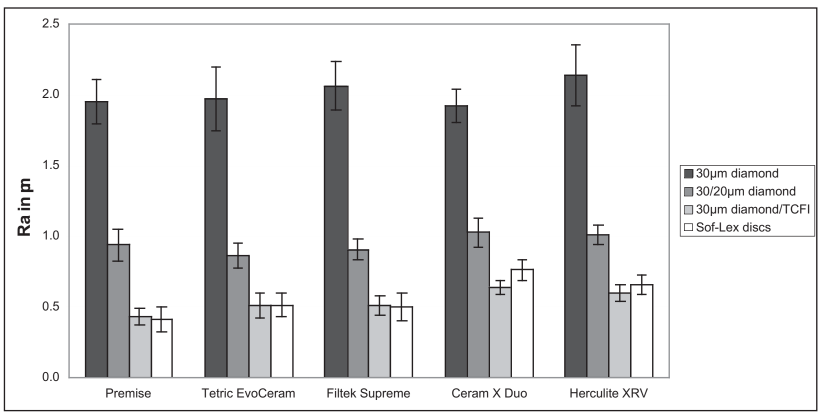

Figure 2A: *Average roughness (Ra).*

Table 3A: *Average roughness (Ra) of four nanoparticle and one hybrid composite after finishing with rigid rotary instruments and polishing with flexible discs (p-values; one-way Anova and post-hoc tests by Scheffé)*

Composite Material	Mean Value with 95% Confidence Interval of n=60 Specimens	Premise	Tetric EvoCeram	Filtek Supreme	Ceram X Duo
Premise	0.933/0.165				
Tetric EvoCeram	0.965/0.160	0.700			
Filtek Supreme	0.996/0.169	0.065	0.683		
Ceram X Duo	1.087/0.133	0.000	0.000	0.001	
Herculite XRV	1.101/0.165	0.000	0.000	0.000	0.979

Table 3B: *Profile length ratio (LR) of four nanoparticle and one hybrid composite after finishing with rigid rotary instruments and polishing with flexible discs (p-values; one-way Anova and post-hoc tests by Scheffé)*

Composite Material	Mean Value with 95% Confidence Interval of n=60 Specimens	Premise	Tetric EvoCeram	Filtek Supreme	Ceram X Duo
Premise	1.340/0.041				
Tetric EvoCeram	1.395/0.040	0.000			
Filtek Supreme	1.376/0.041	0.039	0.569		
Ceram X Duo	1.528/0.029	0.000	0.000	0.000	
Herculite XRV	1.499/0.034	0.000	0.000	0.000	0.150

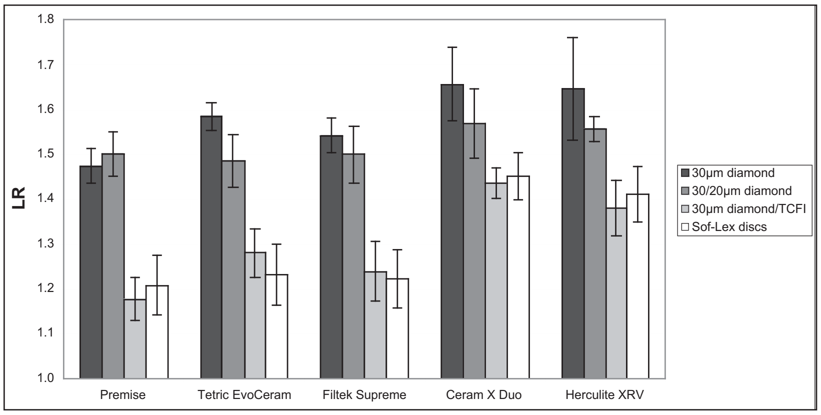

Figure 2B: *Profile length ratio (LR).*

Qualitative Evaluation

Finishing with a 30 µm diamond (FM 1) caused horizontal grooves and left the surfaces of all composites in a rough condition (Figure 3A). Some of the grooves were very pronounced in width and depth. This type of destructive alteration was detected on all types of composites after use of a single 30-µm diamond and was found in 9.4–22.4% of the surfaces (Figure 4).

After application of two diamonds (FM 2), the specimens of all composites still appeared rough, but the depth of the grooves was reduced. Irregularities on the Ceram X Duo surfaces after finishing with two diamonds (Figure 3B) appeared to be more uniform in depth compared to the Herculite XRV specimens (Figure 3C). In 2.6–8.3% of the surfaces, the destructive effects caused by the 30 µm diamond were not completely removed.

After use of a diamond and tungsten carbide bur (FM 3), the surfaces appeared smoother compared to FM 1 and 2 (Figure 3D). Minor roughness was the predominant surface quality on all composites (57.8–83.6%).

Sof-Lex discs achieved a good smoothing effect despite the presence of several minor surface irregularities (Figure 3E). Between 93.5% and 97.4% of the surfaces had minor roughness. Irrespective of the type of surface treatment, several porosities were detected, especially on Ceram X Duo specimens (Figure 3F).

DISCUSSION

The condition of the surface contributes to the success and longevity of composite restorations. The surface quality of composites affects plaque accumulation,[8] physical properties,[5] abrasivity and wear resistance.[9-10] Surface roughness interferes with a patient's comfort in terms of tactile perception,[11] aesthetic appearance[12] and stain resistance of dental resin composites.[4,13]

Rotary instruments for finishing should provide sufficient cutting efficacy for the removal of excess composite material and occlusal adjustment. On the other hand, finishing should not leave the surface in a rough condition, because subsequent polishing measures will be impaired. For this reason, finishing is an important prerequisite for the success of final polishing techniques.[14]

This study assessed composite surface roughness. Several studies emphasize the importance of using more than one method for the evaluation of surface textures.[15-17] For this reason, for qualitative analysis of the composite

Figure 3: *SEM photomicrographs of the surface textures of four nanoparticle and one hybrid composite after finishing and after application of flexible discs; the length of one horizontal bar is equivalent to 100 µm; vertical arrows indicate detrimental surface alteration.*

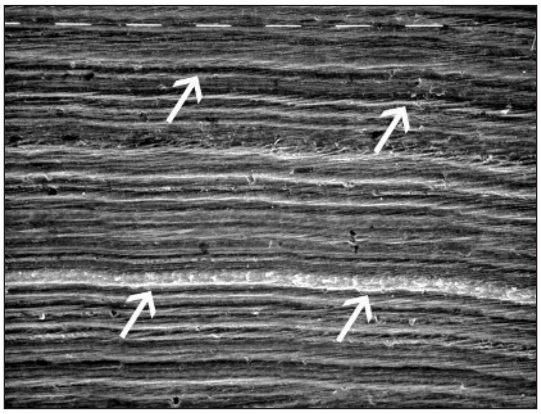

Figure 3A: *Tetric EvoCeram surface after finishing with a 30 µm diamond.*

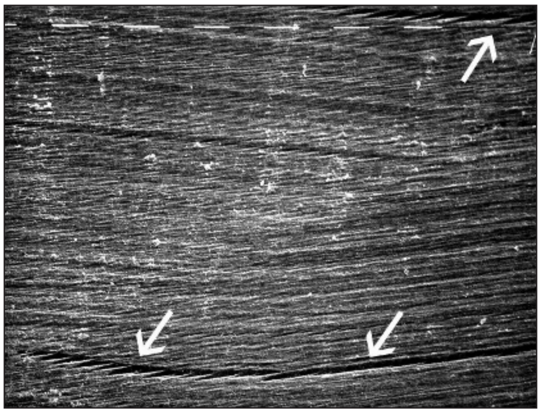

Figure 3B: *Ceram X Duo specimen after finishing with a 30 µm and a 20 µm diamond.*

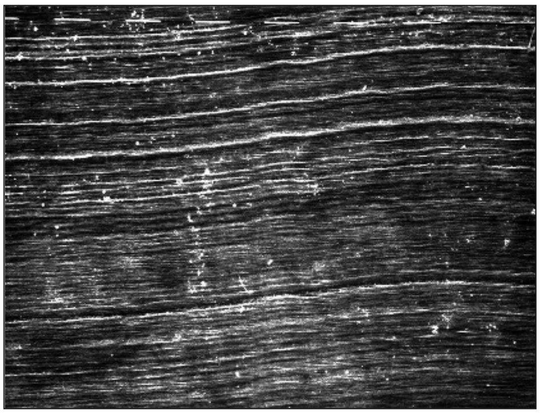

Figure 3C: *Herculite XRV surface with varying roughness after the use of two diamonds.*

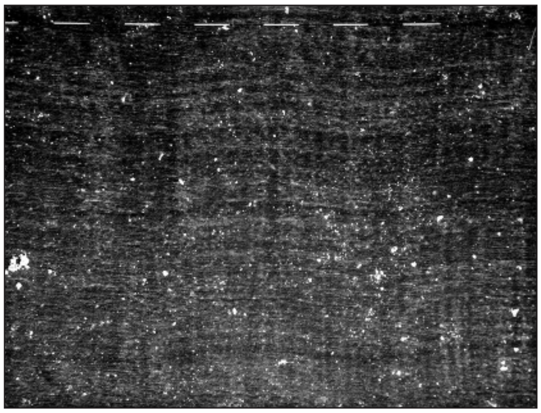

Figure 3D: *Filtek Supreme surface finished by a sequence of 30 µm diamond followed by a tungsten carbide bur.*

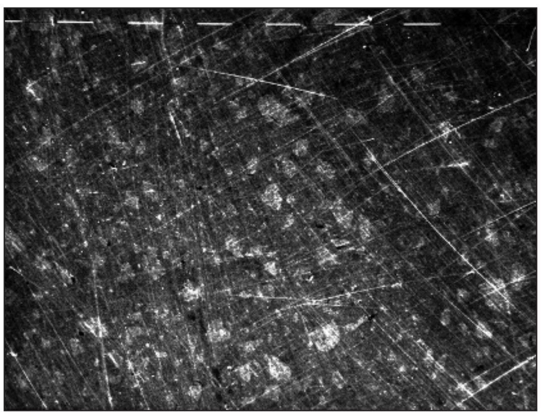

Figure 3E: *Premise specimen after the use of Sof-Lex discs.*

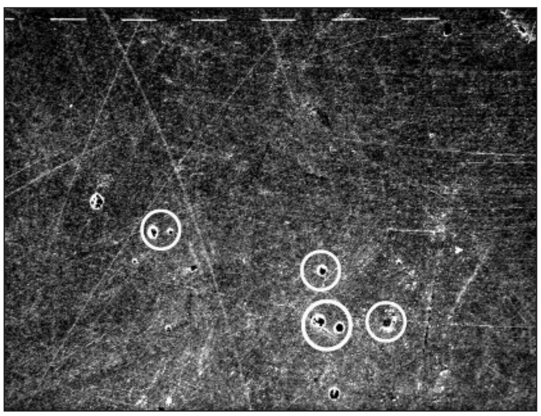

Figure 3F: *Ceram X Duo specimen with several porosities (circular mark) after the application of Sof-Lex discs.*

surfaces, in addition to quantitative evaluation by profilometry, and scanning electron microscopy were included in this study.

With respect to profilometry, the use of different roughness parameters is recommended.[17-18] Average roughness is a vertical parameter and is frequently chosen for the quantitative description of roughness. Profile-length ratio LR is a hybrid parameter that takes into account the vertical and horizontal dimension of roughness.

The importance of using more than one roughness parameter became evident when considering the changes in surface geometry after finishing with one and two diamonds. After the use of a 30 µm diamond, Ra-values were close to 2 µm. After finishing with two diamonds according to FM 2, the average roughness was reduced significantly to values close to 1 µm. Interestingly, the corresponding LR-values were affected only slightly. This can be attributed to the fact that the use of two diamonds did not only reduce the amplitude of profile irregularities, but their number was increased considerably. Only the use of a 30 µm diamond and tungsten carbide bur (FM 3) caused a significant reduction in surface roughness in terms of Ra and LR. On Premise, Ceram X Duo and Herculite XRV surfaces, roughness was even lower after finishing according to FM 3 compared to Sof-Lex discs.

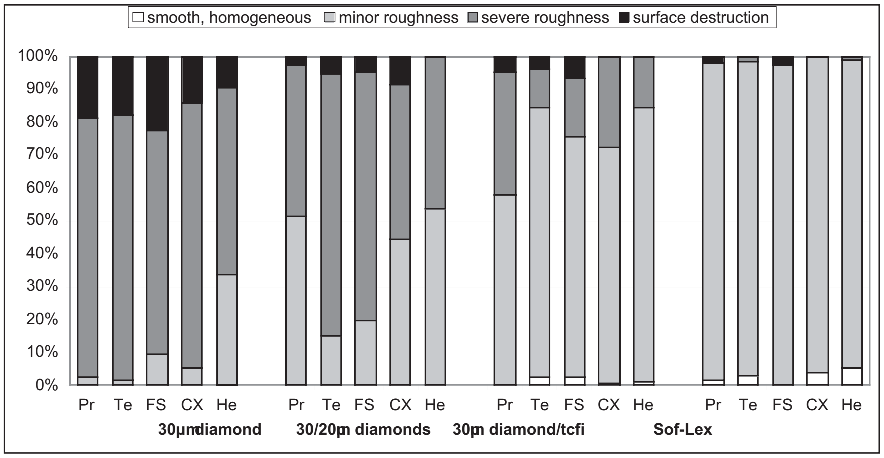

Figure 4: *The portion of different surface roughness gradings of four nanoparticle and one hybrid composite in SEM after finishing and after using Sof-Lex discs (Pr–Premise, Te–Tetric EvoCeram, FS–Filtek Supreme, CX–Ceram X Duo, He–Herculite XRV).*

After finishing and using flexible discs, the nanofilled composites Premise, Tetric EvoCeram and Filtek Supreme had significantly lower surface roughness than the hybrid composite Herculite XRV. Solid filler particles in hybrid or microhybrid materials are considerably larger than nanosized particles. Another point which might be attributed to good surface quality is the fact that nanotechnology enables for obtaining high filler loading. Compared to Herculite XRV, the nanocomposites Premise and Tetric EvoCeram had higher filler content by volume. Thus, it can be expected that, in nanocomposites, a greater number of particles will be present on the surface, establishing a larger contact area with rotating instruments. Moreover, the strong integration of nanoparticles within the composite material might further explain the results of this study. Mitra and others[1] assumed that, due to a strong chemical integration of nanoparticles into the resin matrix, nanocomposites wear by breaking off individual primary particles rather than by breaking off larger particles, as with hybrid composites. This finding was supported by Turssi and others.[3] The authors reported that, in the case of Filtek Supreme, so-called nanoclusters were less prone to be sheared off during wear mechanisms.

Unlike the other nanocomposites, Ceram X Duo did not yield better surface quality than Herculite XRV. There are two points that might contribute to this finding. Ceram X had the lowest volumetric filler content of the composites under investigation. Moreover, surface quality was compromised by a remarkable number of porosities that were detected on Ceram X Duo specimens. Origin of the porosities is unclear. Ceram X Duo was the only composite provided in small compules; whereas, the other materials were provided in larger syringes. The presence of porosities being caused by the fabrication process of specimens could be excluded.

With respect to finishing methods, the use of a 30 µm diamond caused destructive surface alteration on all composites under investigation. In several cases, these deep grooves were not completely removed by the subsequent use of a 20 µm diamond or a tungsten carbide bur. This is problematic, because it might impede further smoothing by final polishing procedures. For this reason, a 30 µm finishing diamond should only be used in cases when extensive removal of composite material is required.

In recent literature, there are no roughness data with respect to the finishing of nanofilled composites with diamonds or tungsten carbide instruments. For this reason, direct comparison of the numerical roughness data of this study with others is difficult.

By considering the results after final polishing, Turssi and others[3] concluded that carbide burs seemed to be better suited for the finishing of Filtek Supreme surfaces compared to diamonds. This finding is in accordance with the results of this study. It is a frequent outcome of several studies that carbide burs achieved smoother surfaces on various types of resin-based composites compared to finishing diamonds.[19-22]

After application of Super-Snap discs on Filtek Supreme specimens, the average roughness (Ra) was 0.33 µm.[23] The use of Sof-Lex discs on Filtek Supreme surfaces achieved Ra-values of 0.125 µm.[24] The corresponding Ra-values of this study were markedly greater than those reported by Silikas and others.[24] This might be explained by methodical differences in the two studies with respect to the type of profilometric pick-up system (mechanical vs optical profilometry) used.

According to the results of this study, nanofilled composites were, with one exception, significantly smoother after finishing with rigid rotary instruments compared to a hybrid material. This could facilitate subsequent polishing with respect to achieving an efficient reduction of the remaining surface irregularities.

CONCLUSIONS

There was a significant effect of the finishing methods and composite materials on surface roughness ($p<0.001$).

With one exception, nanocomposites were significantly smoother after finishing with rigid rotary instruments and after using Sof-Lex discs compared to a hybrid composite.

Finishing with a 30 µm diamond followed by a 12-fluted tungsten carbide bur (FM 3) achieved significantly lower roughness values on all composites compared to the sequence of a 30 µm and 20 µm diamond (FM 2).

Flexible Sof-Lex discs and finishing according to FM 3 caused similar roughness on all composites.

The use of a 30 µm diamond caused detrimental surface alteration on nanoparticle and hybrid composites.

(Received 21 January 2006)

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