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Surface Geometry of Four Nanofiller and One Hybrid Composite After One-step and Multiple-step Polishing

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Clinical Relevance

Two of the four nanocomposites were significantly smoother, while the remaining two had a surface quality similar to that of a hybrid composite. In all cases, a three-step polishing system was more efficient than a two-step or one-step procedure on all composites.

SUMMARY

This study assessed the surface quality of four nanoparticle composites and one hybrid composite after polishing with three different techniques.

Nanocomposites Premise (KerrHawe), Tetric EvoCeram (Ivoclar Vivadent), Filtek Supreme (3M ESPE) and Ceram X Duo (Dentsply) and the hybrid composite Herculite XRV (KerrHawe) were selected. Sixty specimens 7x7 mm each were fabricated from these materials. After light curing, the specimens were treated with 600 grit sandpaper discs. Fifteen specimens of each composite were polished using flexible Sof-Lex discs (3M ESPE). The remaining 45 specimens of each material were prepared with three finishing protocols: a single 30 µm diamond (n=15), a sequence of a 30 µm and a 20 µm diamond (n=15) and a 30 µm diamond followed by a tungsten carbide finishing bur (n=15). Each series of 15 specimens was then subdivided into three groups of five and polished with the Astropol system (Ivoclar Vivadent), OptiShine brushes (KerrHawe) and the Enhance/PoGo system (Dentsply). Quantitative evaluation of surface roughness was done with the help of optical laser stylus profilometry. Average roughness (Ra) was calculated, and the effect of the materials, the finishing regimen and the polishing methods on surface roughness were analyzed by three-way and two-way Anova and Scheffé post-hoc tests. Qualitative evaluation of the surfaces was done with the help of scanning electron microscopy (PSEM 500, Phlipps). Photomicrographs were assessed with respect to surface quality in four gradings.

Surface roughness after polishing was significantly influenced by three factors: composite material (*p*<0.001), finishing protocol (*p*<0.001)

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and polishing method (p<0.001). There were strong interactions between the finishing and polishing methods (p<0.001). Two of the nanocomposites were significantly smoother (p≤0.001), while the other two had a surface quality similar to that of a hybrid composite. Astropol achieved the lowest average roughness on all composites. Except for a combination of a 30 µm diamond and OptiShine brushes, which caused severe roughness, all the polishing methods produced surfaces that were significantly smoother than using the Sof-Lex discs.

INTRODUCTION

Development and advances in the field of nanotechnology have affected dentistry in several ways.[1] Various new composites, based on nanoparticle filler technology, have been developed with the aim of combining the advantages of hybrid and microfilled restorative materials. Nanocomposites claim to provide the aesthetic properties required for anterior restorations, together with a number of mechanical properties necessary for posterior, stress-bearing restorations. Scientific data from *in vitro* investigations indicate that nanofilled resin composites lead to higher surface quality[2-4] and superior polish retention;[5] they also exhibit low wear[3] and increased wear resistance,[6-7] low shrinkage and high strength.[8] Nanofilled resin composites also possess favorable mechanical properties.[5]

Surface quality is important to the longevity of a tooth-colored restoration in the oral cavity. Surface roughness of resin composites affects plaque accumulation,[9] abrasivity and wear kinetics,[10-11] as well as tactile perception.[12] The aesthetic appearance of tooth-colored restorations is of great interest to both the dentist and patient. Surface roughness influences resistance to staining[13-14] and the natural gloss of the restoration.[15-16]

For these reasons, efforts have been made to assess the suitability of several techniques for the finishing and polishing of traditional resin composites. In recent years, attempts were made to achieve a high surface quality by applying one-step polishing systems. It was shown that one-step systems were superior or at least comparable to multi-step techniques for traditional composites,[3,16-19] but, in some cases, the results were product-related.[17,20] The success of one-step polishing systems was closely related to the initial finishing regimen.[3,21]

This study evaluated the effect of three different polishing systems based on one-step and multi-step techniques on the surface quality of four modern nanofilled composites and a traditional hybrid composite.

METHODS AND MATERIALS

Four resin composites, based on nanofiller technology, and one traditional hybrid composite were used for this study (Table 1). Sixty specimens were made from each material, using glass molds. The specimens were 7x7 mm in size and 4 mm thick. Light curing was done for 40 seconds from the top and 40 seconds from the bottom using an Optilux 400 (VCL 401, Demetron, Danbury, CT, USA). The polymerization unit was controlled with the help of a curing radiometer (Model 100, P/N 10503, Demetron), ensuring a constant light output intensity >600 mW/cm^2. After curing, all specimens were subjected to sandpaper treatment (600 grit, Leco Corporation, St Joseph, MI, USA). The sandpaper discs were mounted on a rotating polishing device (automatic polishing apparatus A 250, Jean Wirtz, Duesseldorf, Germany). The sandpaper treatment was done under water-cooling and was terminated after 30 seconds.

Medium to super-fine Sof-Lex discs were then used to treat 15 specimens of each material. The remaining 45 specimens of each material were randomly assigned to three groups of 15 specimens, which were subjected to the following finishing protocols:

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

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

1. 30 µm finishing diamond (#806 314 290 514 014, Brasseler, Savannah, GA, USA); n=15
2. a sequence of a 30 µm and 20 µm finishing diamond (#806 314 290 504 014, Brasseler); n=15
3. 30 µm diamond followed by a 12-fluted tungsten carbide finishing bur (#500 314 290 072 014, Brasseler); n=15

The finishing was done with a new red-ring handpiece 24 LN (Intramatic Lux 2, KaVo, Biberach, Germany) at 40,000 rpm under three-way water-cooling. A new instrument was used after every five specimens.

In a further step, 15 specimens of each finishing group were subdivided into three subgroups of five each. The specimens from the first subgroup were polished using the Astropol system, while the specimens from the second subgroup were polished with OptiShine brushes, and the specimens from the third subgroup were polished using the Enhance/PoGo system (Figure 1). Polishing included a three-step system (Astropol), a two-step technique (Enhance/PoGo) and a one-step brush application (OptiShine). A new polishing instrument was used after every application. Polishing was done with a new blue-ring handpiece 20 LH (Intramatic Lux 3, KaVo) according to the manufacturer's recommendations. Details of the products and applications are shown in Table 2.

The application time was limited to 30 seconds for each finishing and polishing instrument. The samples of each material and each finishing and polishing method were distributed equally between two operators, who performed rotary instrumentation manually. Selection of the type of composite material and the finishing and polishing method followed a randomized protocol. During manual surface treatment, the type of composite was blind.

After polishing, the composite surfaces were assessed quantitatively by profilometry and qualitatively by scanning electron microscopy (SEM). Surface roughness measurements were made by optical profilometry with the help of a Focodyn laser-stylus pick-up system (Rodenstock, Munich, Germany). A laser beam 1 µm in diameter was focused on the surface of the specimens. Profile irregularities caused vertical dislocation of the laser pick-up. The extent of the vertical shift was then transformed into an electronic signal. Surface roughness data were collected and processed by the central unit S8P (Mahr, Goettingen, Germany). The measuring apparatus was located on an air-damped platform (VW-3036-OPT-0330, Newport, Fountain Valley, CA, USA). Each surface was scanned by nine parallel tracings, which were generated automatically. The side-shift between two tracings was 0.219 mm. The measuring conditions were:

- transverse length (L_T) = 1.75 mm
- sampling length (L_M) = 1.25 mm
- vertical band width (VB) = ± 62.5 µm
- Gauss profile filter (λc) = 0.25 mm
- evaluated area = 1.25 x 1.75 mm

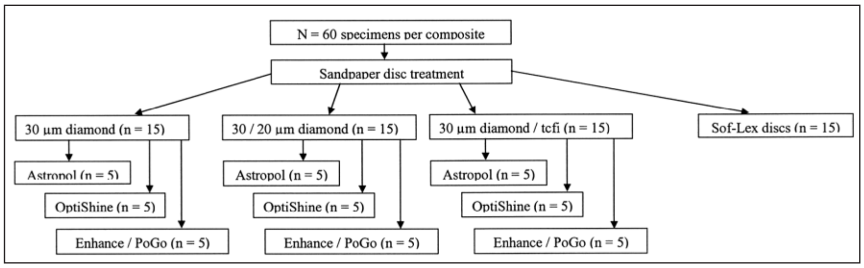

Figure 1: *Study design showing distribution of the specimens among the finishing groups and polishing subgroups (tcfi–12-fluted tungsten carbide finishing instrument).*

Table 2: *Details of the Polishing Systems and Their Application Modes (based on information and recommendations given by manufacturers)*

Product	Manufacturer	Order #	Matrix	Abrasives	Particle Size	Shape	RPM/# of Steps	Water Cooling
Astropol	Ivoclar Vivadent, Ellwangen, Germany	557617 (F) 557619 (P) 557623 (HP)	Rubber	Si-carbide Al_2O_3, TiO_2, FeO diamond (HP)	36.5 µm (F) 12.8 µm (P) 3.5 µm (HP)	Cup	8500/ 3 Steps	Yes (2-way)
OptiShine	KerrHawe, Bioggio, Switzerland	70402660	Plastic material	Si-carbide	5 µm	Brush-Cup	5000/ 1 Step	No
Enhance/ PoGo	Dentsply, Konstanz, Germany	662020X	Polyurethane-dimethacrylate (PoGo)	Al_2O_3 (Enhance) diamond (PoGo)	40 µm (Enhance) 7 µm[1] (PoGo)	Cup	8000/ 2 Steps	No
Sof-Lex Discs	3M ESPE Dental Products, St Paul, MN, USA	1982 M 1982 F 1982 SF	Flexible Discs	Al_2O_3	29 µm (M) 14 µm (F) 5 µm (SF)	Flexible Disc	3000/ 3 Steps	Yes (2-way)

[1]–*based on measurement by own SEM study*

Surface roughness was described by the arithmetic mean of the absolute ordinate values (average roughness Ra, as per ISO 4287).[22] Ra values were distributed normally; statistical analysis was carried out by three-way and two-way Anova and post-hoc tests according to Scheffé (SPSS for Windows, version 11.5.1).

For SEM evaluation, 20 specimens of each composite were randomly selected to represent each finishing and polishing method. The specimens were gold-coated with the SCD 040 (Bal Tec, Balzers, Liechtenstein) sputtering device. The SEM study was performed with a PSEM 500 (Philips, Eindhoven, Netherlands) at a working tension of 25 kV. Photomicrographs of each surface were taken at 80x original magnification. Photoprints 16x12 cm in size were used. They were subdivided into 48 squares, with each square being assessed separately with respect to surface roughness, using four gradings:

- smooth, homogeneous surface
- minor roughness
- severe roughness
- detrimental surface area

During SEM examination, the type of composite and polishing method were blind. After calibration in qualitative evaluation of roughness, assessment of the photomicrographs was carried out by two individuals.

RESULTS

Quantitative Evaluation

Surface roughness was significantly affected by the composite materials ($p<0.001$), the finishing methods ($p<0.001$) and the polishing techniques ($p<0.001$).

The greatest degree of roughness for all composites resulted from OptiShine brushes after finishing with a single 30 µm diamond. The difference from the other methods was so pronounced that this method was excluded from the statistical analysis. In a comparison of the mean values of the remaining 55 specimens of each composite material (Figure 2), the lowest average roughness was found on Premise (Ra=0.266 µm). The differences from the other four materials were significant (Table 3). Tetric EvoCeram specimens were significantly smoother compared to Ceram X Duo, Filtek Supreme and Herculite XRV. The greatest Ra values were measured on Ceram X Duo specimens (Ra=0.398 µm), but the differences to Filtek Supreme and Herculite XRV were only small and of no significance.

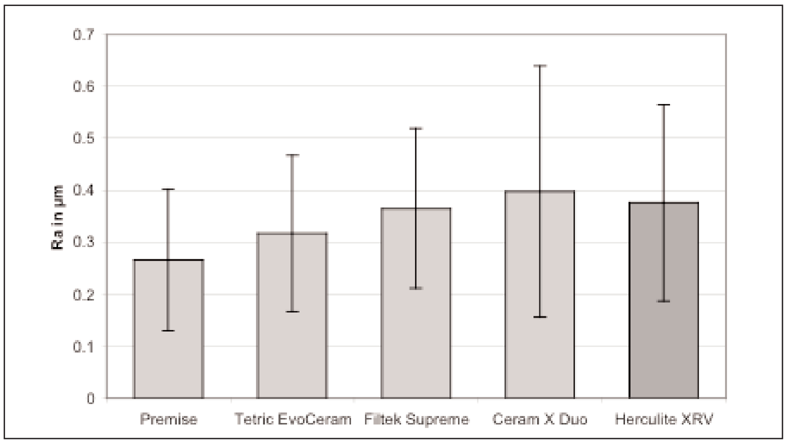

Figure 2: *Overall roughness of four nanoparticle composites and one hybrid composite after finishing and polishing (each bar represents mean value and standard deviation of n=55 specimens); data of specimens treated with a 30 µm diamond and OptiShine brushes have been excluded.*

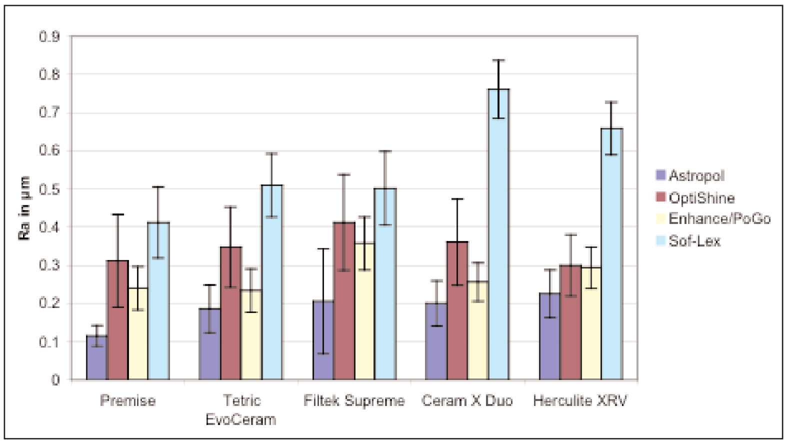

Figure 3: *The effect of four polishing methods on four nanofiller and one hybrid composite with respect to average surface roughness (Ra); each bar represents mean value and standard deviation of n=15 specimens; OptiShine represents n=10 specimens (after exclusion of the specimens treated with a 30 µm diamond).*

Table 3: *Average Roughness (Ra; mean of n=55 specimens per material) of Four Nanoparticle Composites and One Hybrid Composite After Polishing (*p*-values derived from two-way Anova and post-hoc tests according to Scheffé)*

Composite Material	Ra (Mean/SD)	Herculite XRV	Ceram X Duo	Filtek Supreme	Tetric EvoCeram
Premise	0.266/0.136	0.000	0.000	0.000	0.009
Tetric EvoCeram	0.317/0.151	0.001	0.000	0.018	
Filtek Supreme	0.365/0.154	0.962	0.236		
Ceram X Duo	0.398/0.242	0.643			
Herculite XRV	0.376/0.188				

Table 4: *Average Roughness (Ra; mean of n=25 specimens [method 1-9] and n=75 [method 10]) of Four Nanoparticle Composites and One Hybrid Composite after Finishing and Polishing (p-values derived from two-way Anova and post-hoc tests according to Scheffé); fd–finishing diamond, tcfi–tungsten carbide finishing bur*

Method	Ra (Mean/SD)	10	5	3	8	6	9	1	4
30 µm fd/tcfi/ Astropol (7)	0.174/0.074	0.000	0.000	0.000	0.003	0.007	0.037	0.990	1.000
30/20 µm fd/ Astropol (4)	0.185/0.068	0.000	0.000	0.000	0.017	0.034	0.129	1.000	
30 µm fd/ Astropol (1)	0.200/0.110	0.000	0.000	0.003	0.114	0.183	0.441		
30 µm fd/tcfi/ PoGo (9)	0.258/0.065	0.000	0.000	0.811	1.000	1.000			
30/20 µm fd/ PoGo (6)	0.270/0.068	0.000	0.000	0.966	1.000				
30 µm fd/tcfi/ OptiShine (8)	0.274/0.073	0.000	0.000	0.988					
30 µm fd/ PoGo (3)	0.301/0.079	0.000	0.000						
30/20 µm fd/ OptiShine (5)	0.419/0.100	0.000							
Sof-Lex (10)	0.569/0.150								
30 µm fd/ OptiShine (2)	1.756/0.229	excluded from post-hoc tests							

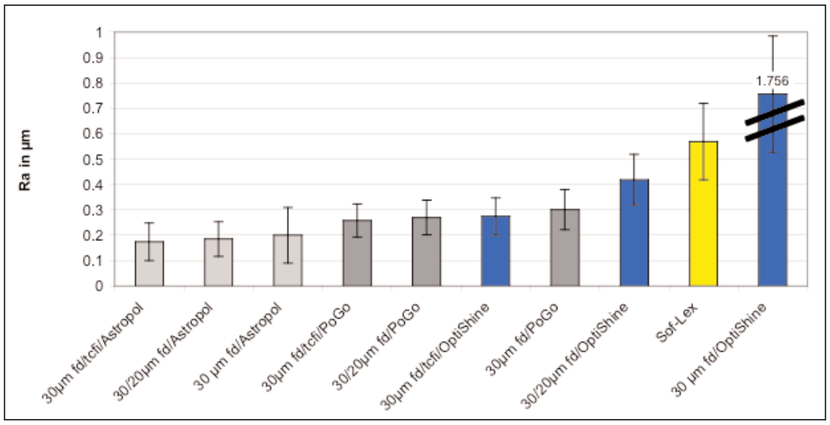

Figure 4: *Average surface roughness achieved by 10 finishing and polishing regimes after application on four nanoparticle composites and one hybrid composite (mean value and standard deviation); each bar represents n=25 specimens, the Sof-Lex bar represents n=75 specimens. Fd–finishing diamond, tcfi–12-fluted tungsten carbide finishing instrument.*

The global effects of the four polishing methods on the composite materials are shown in Figure 3. With the exception of the above-mentioned example (OptiShine brushes after finishing with a single 30 µm diamond), the greatest degree of roughness for all composite materials was found after application of Sof-Lex discs. Astropol led to the smoothest surfaces on all types of composites. In the case of the Herculite XRV specimens, the average roughness after applying OptiShine and Enhance/PoGo was similar. For the four nanocomposites, the average surface roughness resulting from Enhance/PoGo was lower than for OptiShine.

There was significant interaction between finishing and polishing ($p<0.001$). For this reason, the results of the three polishing systems were analyzed separately with respect to the three different finishing methods (Table 4). The smoothest surfaces were obtained after using Astropol polishers (Figure 4). In this case, the finishing method was only of moderate influence on the resulting surface roughness; pretreatment with a 30 µm diamond and a tungsten carbide bur led to the best results. Surface roughness after Enhance/PoGo was greater than with Astropol. The level of significance between Astropol and PoGo depended on the type of finishing pre-treatment; average roughness after Enhance/PoGo was significantly greater than with Astropol, if Astropol was used after finishing with a 30 µm diamond and a tungsten carbide bur. Specimens treated with OptiShine brushes were significantly smoother if the initial finishing was done with a 30 µm diamond and a tungsten carbide bur instead of two finishing diamonds. Ra values after the use of OptiShine brushes and two finishing diamonds were significantly higher than with all other methods, except Sof-Lex discs.

Qualitative Evaluation

Qualitative assessment of the SEM photomicrographs accorded well with the quantitative results. The highest level of roughness for all composites was observed after the application of OptiShine brushes (Figure 5). The abrasive potential of an OptiShine brush proved to be relatively low and, thus, the surface irregularities following finishing with a 30 µm and a 20 µm diamond were not sufficiently removed (Figure 6). Specimen surfaces after treatment with flexible Sof-Lex discs were mainly characterized by the remaining minor grooves and surface irregularities (Figure 7). Astropol polishers had the greatest smoothing effect and achieved the largest number of smooth and homogeneous surfaces (Figure 8), ranging from 20%-50%. The Enhance/PoGo polishers generally yielded surfaces with minor roughness between 51%-89%, with smooth surfaces ranging from 4%-45% (Figure 9). All in all, the amount of surface destruction was low and of no relevance for any of the composites and polishing methods.

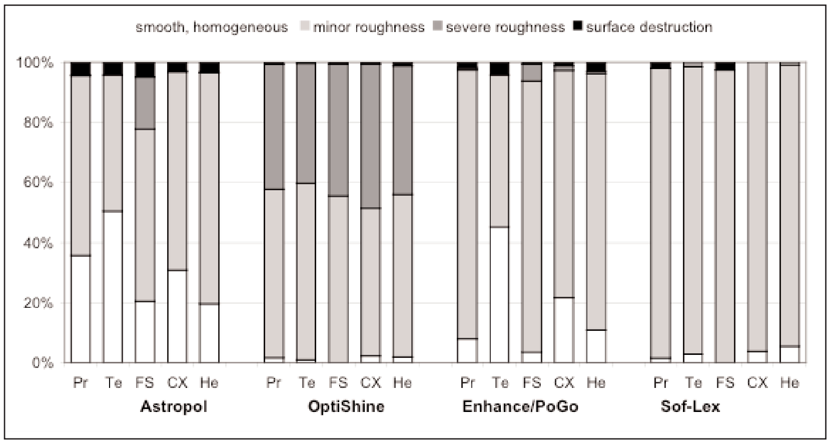

Figure 5: *Surface roughness gradings of four nanoparticle composites and one hybrid composite in SEM after polishing with one-step and multiple-step methods; Pr–Premise, Te–Tetric EvoCeram, FS–Filtek Supreme, CX–Ceram X Duo, He–Herculite XRV.*

DISCUSSION

In addition to making possible the synthesis of nanosized filler particles, nanotechnology is believed to have a beneficial effect on the stable chemical integration of such particles within the composite matrix.[5] This is thought to contribute to the low wear rates of nanoparticle composites.[3,5-6] In the case of surface alteration caused by contact with abrasive polishing instruments, a surface that is composed of nanoparticles is less likely to suffer particle loss. This might explain the low surface roughness found on Premise and Tetric EvoCeram specimens. However, the results also showed that the four nanocomposites did not represent a homogeneous group with respect to surface roughness. Two of the nanoparticle composites had a surface quality that was no better than that of a traditional hybrid composite. Thus, there must be another factor influencing the behavior of a nanoparticle surface during polishing. The roughness data after polishing correlate well with the filler content in terms of weight and volume of the composite materials under investigation. Premise and Tetric EvoCeram were significantly smoother than the other materials; their volumetric filler content (Premise 69% and Tetric EvoCeram 68%, Table 1) was far greater than the filler content of Filtek Supreme (59.9%), Ceram X Duo (57%) and Herculite XRV (59%).

It was shown that a greater number of polishing steps produced better smoothing effects. A three-step system (Astropol) achieved the best results; whereas, a two-step (Enhance/PoGo) and one-step system

Figure 6: *Severe roughness on the surface of a Filtek Supreme specimen after finishing with a 30 µm and 20 µm diamond and application of OptiShine brushes.*

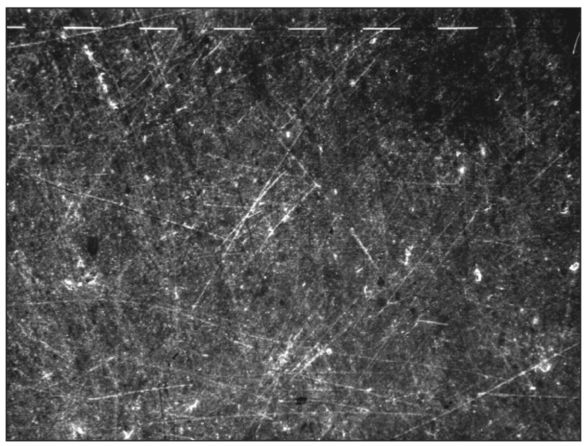

Figure 7: *Surface of a Tetric EvoCeram specimen with prevailing minor roughness after treatment with Sof-Lex discs.*

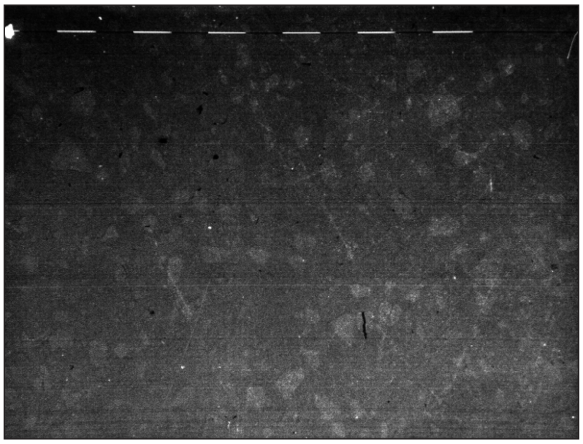

Figure 8: *Smooth and homogeneous surface of a Premise specimen after finishing with a 30 µm diamond and a 12-fluted tungsten carbide bur and polishing with Astropol.*

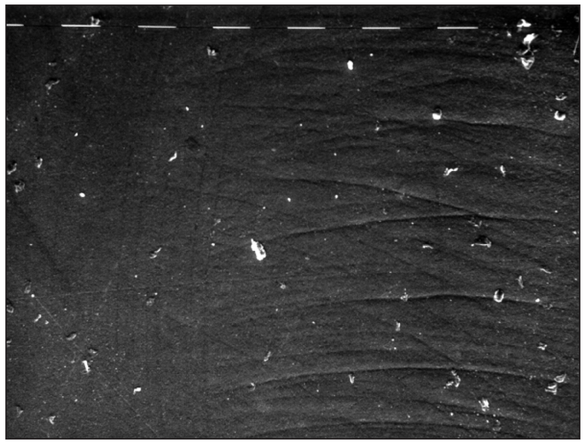

Figure 9: *Smooth areas, areas of minor roughness and areas of severe roughness on a Ceram X Duo specimen after finishing with two diamonds and polishing with Enhance/PoGo cups.*

(OptiShine) were consecutively less efficient. Indeed, in the current study, at least four finishing and polishing steps were required to achieve high surface quality.

The influence of the initial finishing method on final surface roughness increased as the number of subsequent polishing steps decreased. The influence of the finishing method on surface roughness after polishing was strongest with OptiShine brushes.

The use of a 30 µm diamond and OptiShine brushes caused severe roughness with all composites. Obviously, this sequence of finishing and polishing was inappropriate. With respect to Ra, there was a clearly pronounced and highly significant difference with the other methods (about three times as high as the results after application of Sof-Lex discs and about 10 times as high compared to the Astropol system). Because such a great heterogeneity in roughness data would have had a negative influence on the discrimination power of the statistical analysis, the respective Ra values for OptiShine were excluded.

Except for OptiShine after a 30 µm diamond, all finishing and polishing sequences achieved significantly smoother surfaces on the composites than was the case with flexible Sof-Lex discs. This would indicate that the polishing systems investigated during this study were superior in smoothing efficiency regarding microhybrid and nanoparticle resin composites.

For this study, one-step, two-step and three-step polishing systems were chosen. Per definition, PoGo is a one-step method and, indeed, some authors use the system without any pre-treatment.[17,19] On the other hand, the manufacturer recommends pre-treatment with the Enhance system. For this reason, the authors of this study classified and applied Enhance/PoGo as a two-step method. The current results do not indicate whether pre-treatment with Enhance cups has a beneficial effect on surface quality.

Several factors influence the outcome of surface roughness evaluation studies. Manual preparation is frequently applied, because it better simulates clinical conditions. When finishing and polishing, there is a wide range of loads, speeds and times practitioners use.[23] It is generally accepted that preparation under different conditions might create varying surface quality.[15] Variations in the experience and skill of operators may equally affect the final level of surface roughness. Furthermore, daily performance by the individual operator is not constant. Therefore, in the current study, in order to render the roughness values as more representative of finishing and polishing, they were performed by two individuals.

Few studies in the literature deal with the surface quality of nanoparticle composites. Comparing numerical data of surface roughness derived from different studies is difficult, because of several factors that might influence the outcome in each case. Three studies that were conducted on polishing Filtek Supreme specimens reported lower Ra values than those of this study. Filtek Supreme specimens were polished to Ra=0.33 µm after application of Super-Snap discs.[2] After using Sof-Lex discs on Filtek-Supreme, the average roughness (Ra) was 0.125 µm.[4] PoGo diamond cups achieved Ra values of 0.11 µm after finishing with tungsten carbides and Ra=0.28 µm using finishing diamonds on Filtek Supreme.[3] In accordance with the results of this study, roughness after polishing with PoGo was lower if initial finishing was performed with a carbide instrument. After polishing with Sof-Lex discs, Filtek Supreme surfaces were smoother than two, but rougher than one microhybrid.[4] The surface roughness of Tetric EvoCeram polished with Astropol was lower than one microhybrid but higher than one microfill composite.[15]

The effect of multi-step and one-step polishing systems on surface roughness is still being discussed. In the case of anterior resin composites, one-step diamond polishers achieved the smoothest finish, compared to flexible discs and the Enhance system.[18] On microhybrid and microfilled composites, one-step diamond polishers were more efficient than flexible discs and the Astropol system.[16] Other investigations reported no significant differences between one-step, two-step and multi-step systems in terms of surface roughness.[17,19,24] In accordance with the current results, Watanabe and others showed that surface finish using multiple-step polishing systems was superior to that obtained with one-step systems.[25] The PoGo system is very sensitive to the mode of application, because it requires polishing at two different loads. Therefore, with this system, inter-individual differences with respect to manual application and polishing could have a greater effect on results than is the case with other methods. Astrobrush polishers, which are similar to OptiShine brushes in composition and application, yielded the least favorable results on microhybrids.[24]

CONCLUSIONS

Nanoparticle composites did not constitute a homogeneous group regarding surface roughness after polishing. Two nanocomposites were significantly smoother per se, and two other nanoparticle composites had a surface roughness similar to that of a hybrid composite.

Three-step rubber polishers were more efficient than two-step and one-step polishing methods on nanoparticle and hybrid resin composites.

The initial finishing regimen had a greater impact on surface roughness if subsequent polishing was performed with a one-step method compared to a multiple-step method.

Silicon-carbide polishing brushes were inefficient after finishing with a single 30 µm diamond. All other finishing and polishing regimens were superior to flexible Sof-Lex discs in terms of average roughness.

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