ORIGINAL RESEARCH

Effects of Toothbrush Hardness on *in vitro* Wear and Roughness of Composite Resins

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ABSTRACT

Aim: To investigate and compare the effects of toothbrushes with different hardness on abrasion and surface roughness of composite resins.

Materials and methods: Toothbrushes (DENT. EX Slimhead II 33, Lion Dental Products Co. Ltd., Tokyo, Japan) marked as soft, medium and hard, were used to brush 10 beam-shaped specimens of each of three composites resins (Venus [VEN], Venus Diamond [VED] and Venus Pearl [VEP]; HeraeusKulzer) with standardized calcium carbonate slurry in a multistation testing machine (2N load, 60 Hz). After each of five cycles with 10k brushing strokes the wear depth and surface roughness of the specimens were determined. After completion of 50k strokes representative samples were inspected by SEM. Data were treated with ANOVA and regression analyses (p < 0.05).

Results: Abrasion of the composite resins increased linearly with increasing number of brushing cycles ($r^2 > 0.9$). Highest wear was recorded for VEN, lowest for VED. Hard brushes produced significantly higher wear on VEN and VEP, whereas no difference in wear by toothbrush type was detected for VED. Significantly highest surface roughness was found on VED specimens (Ra > 1.5 µm), the lowest one on VEN (Ra < 0.3 µm). VEN specimens showed increased numbers of pinhole defects when brushed with hard toothbrushes, surfaces of VEP were uniformly abraded without level differences between the prepolymerized fillers and the glass filler-loaded matrix, VED showed large glass fillers protruding over the main filler-loaded matrix portion under each condition.

Conclusion: Abrasion and surface roughness of composite resins produced by toothbrushing with dentifrice depend mainly on the type of restorative resin. Hardness grades of toothbrushes have minor effects only on abrasion and surface roughness of composite resins. No relationship was found between abrasion and surface roughness.

Clinical significance: The grade of the toothbrush used has minor effect on wear, texture and roughness of the composite resin.

Keywords: Laboratory research, Toothbrush, Toothpaste, Composite resin, Wear, Surface roughness.

INTRODUCTION

Toothbrushing is the most common measure of oral hygiene and a daily habit in developed countries.[1] Mostly consumers consider the selection of a toothbrush stiffness grade a matter of personal preference, although dentists commonly recommend soft or medium grade brushes, regarding the potential risk of damaging gingiva and oral mucosa using hard brushes.

The International Organization for Standardization defines toothbrush stiffness by filament stiffness grades of toothbrush heads that is converted into stiffness categories soft, medium and hard.[2] Manufacturers classify their products accordingly.

Since toothbrushing is generally performed with toothpaste it appears reasonable to focus on the interaction of brush and abrasive paste. Research has shown that toothbrushing without dentifrice had almost no effect on wear of hard tissues.[3-6] Commonly, it is believed that hard toothbrushes cause more wear on dental hard tissues and restorative materials than soft ones. However, unexpectedly several research reports confirmed, that hard toothbrushes in combination with abrasive toothpaste caused less abrasion than soft brushes with dentifrice.[5,6] This apparent contradiction is explained by the assumption that soft toothbrushes retain more toothpaste and thus create a larger surface contact on the substrate.[5] Other authors claim that the hardness grade of the toothbrush has no effect on toothpaste

abrasivity.[7,8] To make things even more confusing, a laboratory evaluation of the abrasion capacity of four soft toothbrushes carrying a standard dentifrice, showed that in spite of the same classification of the brushes differences in abrasion potential were found.[9]

It is well documented, that brushing with toothpaste roughens the surface and causes wear of composite resin restorations, although to different extent with different composite classes.[10,11] Wear and roughness of resin-based restorations may impair the esthetic appearance of the restorations and might have an influence on plaque accumulation and staining. With the introduction of new composite resins and manufacturers' claims of high wear resistance and surface smoothness, *in vitro* evaluation of such new products using simulated toothbrushing is desirable.

The aim of the present *in vitro* investigation was therefore to study the effect of different grades of toothbrushes in combination with a standardized abrasive slurry representing toothpaste on wear, surface texture and roughness of three composite resins marketed from the same manufacturer. The null hypothesis tested was that the grade of the toothbrush used had no effect on wear, texture and roughness of the composite resin.

MATERIALS AND METHODS

The three composite resins selected for the study, manufactured by HeraeusKulzer, are shown in Table 1 together with their compositions and filler contents. Venus (VEN) is a conventional hybrid-type composite, Bis-GMA/TEGDMA based, loaded with fine-ground glass with an average grain size of 0.7 μm and dispersed SiO_2 (0.04 μm). Venus Diamond (VED) and Venus Pearl (VEP) are nano-hybrid type composites with the same resin mixture of TCD-DI-HEA/UDMA. The main difference between the products is the filler component and the filler grain size. VED contains ground glass and SiO_2 nanofiller (5 nm to 20 μm), whereas VEP in addition contains prepolymer particles and a narrower grain size distribution (5 nm to 5 μm). The filler content of VEP is 5% (weight) less than in VED.

Toothbrushes from the same manufacturer, specified as hard, medium and soft respectively, were used (DENT. EX Slimhead II 33, Lion Dental Products Co. Ltd., Tokyo, Japan).

Specimen Preparation

Composite resin beams (3 × 3 × 12 mm) were produced in Teflon molds, placed on a Mylar strip covered glass plate. The molds were slightly overfilled, the excess material was covered with another Mylar strip and pressed flush under a parallel hand press. The specimens were light activated from one surface (3 × 12 mm) only for 60 seconds using the LED unit Translux Power Blue (650 mW/cm^{-2}; HeraeusKulzer, Hanau, Germany). The light guide was moved in slow scanning motion and in contact with the Mylar strip over the composite material. The cured beams were removed from the molds, marked on the side that was exposed for light, and stored for 24 hours in deionized water at room temperature before testing.

Toothbrush Wear Testing

Thirty specimens were produced from each of the three composites and divided into three groups with 10 beams each, allocated to the different toothbrushes. For each of the 9 composite/toothbrush testing groups 10 specimens were mounted with the light-activated surface upside in row and with close contact to each other on an acrylic resin plate (48 × 10 × 3 mm). Then, next to the composite beams three acrylic beams of the same dimensions were placed and glued to the mounting plate. Finally, the exposed target surfaces were wet-ground successively on SiC-paper grits #2400 and #4000 for 60 seconds each, to ensure that all beam surfaces were exactly in the same plane.

For tooth brushing, a multistation custom made abrasion-testing machine (Tokyo Giken Inc., Tokyo, Japan), equipped with five lines of reciprocating tooth brush heads was used. The holders with the composite specimens were mounted underneath the toothbrush heads. The one mm wide ends of

Material (code)	Batch/ expiry	Manufacturer	Composition	Filler content wt%/vol%
Venus (VEN)	010402/ 2014-11	Heraeus Kulzer, Hanau, Germany	Matrix: Bis-GMA, TEGDMA Filler: Ba-Al-F-glass (average grain size: 0.7 μm; max.< 2 μm), dispersed SiO_2: (average grain size: 0.04 μm)	77/61
Venus Diamond (VED)	010042/ 2014-12	Heraeus Kulzer, Hanau, Germany	Matrix: TCD-DI-HEA, UDMA Filler: Ba-Al-F-glass, SiO_2 nanofiller (grain size: 5 nm to 20 μm)	81/64
Venus Pearl (VEP)	VP301110/ 2014-05	Heraeus Kulzer, Hanau, Germany	Matrix: TCD-DI-HEA, UDMA Filler: Ba-Al-F-glass, prepolymerized filler, SiO_2 nanofiller (grain size: 5 nm to 5 μm)	76/59* (*58% inorg.)

Table 1: Composite resin materials investigated

Bis-GMA: bisphenol A diglycidylether methacrylate; UDMA: 7,7,9-Trimethyl-4,13-dioxo-3,14-dioxa-5,12-diaza-hexadecane-1,16-diylbismethacrylate; TEGDMA: 3,6-Dioxaoctamethylendimethacrylate; TCD-DI-HEA: Bis-(acryloyloxymethyl)tricyclo [5.2.1.02,6] decane

the samples were covered with a metal frame, shielding for toothpaste slurry abrasion in order to preserve unambiguous reference planes for wear track determination after brushing. Instead of commercial toothpaste aqueous slurry of 150 g calcium carbonate (Calcium Carbonate 030-00385, Wako Pure Chemical Industries. Ltd., Osaka, Japan) dispensed in 100 ml of water was used as abrasive medium. The powder is specified as 99.5% (mass/mass) purity and 5.2 μm average particle size.

The holders with the mounted specimens were immersed in the abrasive slurry for 5 times repeated 10,000 forth-and-back bushing strokes (60 Hz) perpendicular to the lengths of the composite beams and under static load of the toothbrush heads of 2 N. Following each 10,000 stroke brushing cycle the specimens were taken up for wear and roughness measurement and the abrasive slurry was changed. Abrasion testing was done at ambient laboratory atmosphere (23 ± 2°C; 50 ± 15% relative humidity).

Measurement of Depth of Wear and Surface Roughness

Prior to toothbrushing the surface roughness of each mounted and fine-ground composite beam was measured with a profilometer (Surfcom 480A, Tokyo Seimitsu Co., Ltd, Tokyo, Japan) fitted with a diamond pick-up system (tip radius: 5 μm; load: 4 mN). For determination of the maximum depth of surface wear the stylus traversed 11 mm centrally on the specimen from one shielded end to the opposite one. The maximum depth of wear in μm was then determined graphically from the registered profile as the largest deviation from the line connecting the reference planes to the deepest portion of the stylus track.

The surface roughness (Ra in μm) was determined in the middle of the specimen close to the centerline from a 1.25 mm trace length (0.6 mm/s; cut-off 0.25 mm).

Abrasion depth and surface roughness were measured after each of the five 10k brushing cycles.

The data were statistically evaluated with regression analyses, univariate ANOVA and post hoc testing ($p \leq 0.05$).

Inspection of the Surface Texture by Scanning Electron Microscopy (SEM)

After 50,000 brushing cycles one random sample of each composite/toothbrush combination was selected for SEM examination. Following sputter coating with Pt, photographs were taken from the center of the specimen at 1,000-fold magnification (10 kV).

RESULTS

Figures 1 to 3 show the wear depths of the three composite materials in combination with the three toothbrush grades
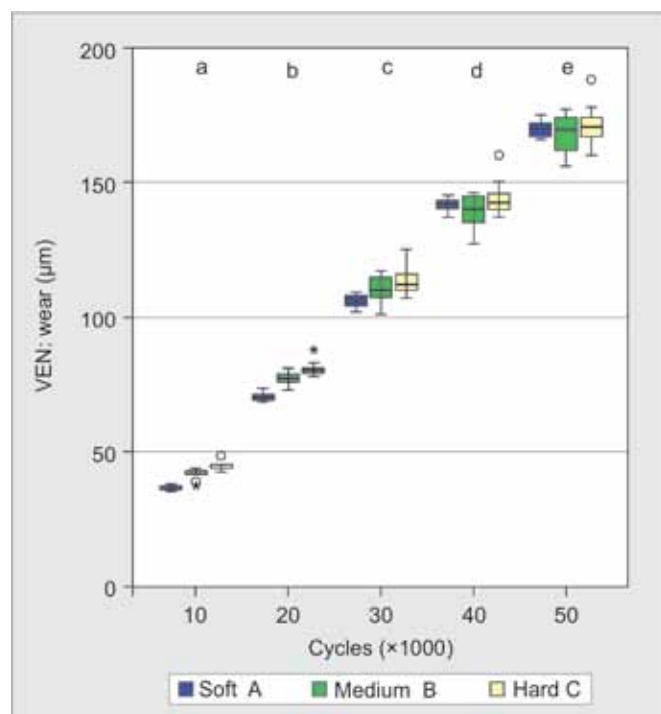

Fig. 1: Box-and-whisker plots of depth of wear of VEN after brushing with soft, medium and hard toothbrushes with calcium carbonate slurry for 50k brushing cycles. Lower-case letters denote significantly different groups by brushing cycles in ascending order, whereas upper-case letters describe significant differences between the toothbrushes used in ascending order (p < 0.05)
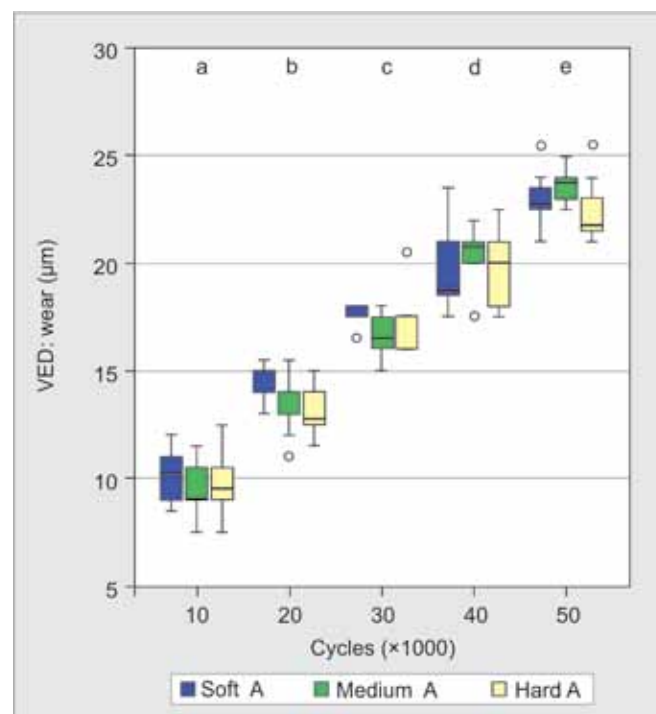

Fig. 2: Box-and-whisker plots of depth of wear of VED after brushing with soft, medium and hard toothbrushes with calcium carbonate slurry for 50k brushing cycles. Lower-case letters denote significantly different groups by brushing cycles in ascending order. Toothbrush types showed no significant differences as indicated by upper-case letters (p < 0.05)
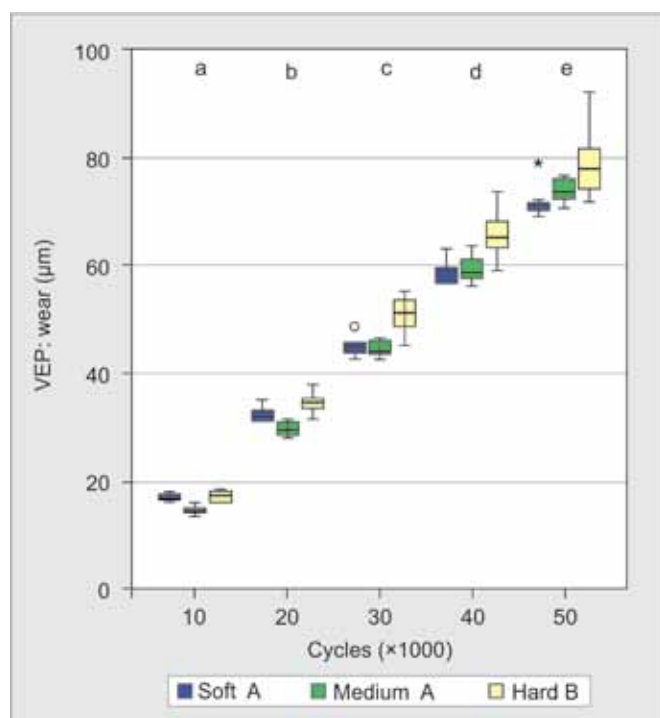
Fig. 3: Box-and-whisker plots of depth of wear of VEP after brushing with soft, medium and hard toothbrushes with calcium carbonate slurry for 50k brushing cycles. Lower-case letters denote significantly different groups by brushing cycles in ascending order. Hard toothbrushes produced significantly larger wear than soft and medium types ($p < 0.05$)
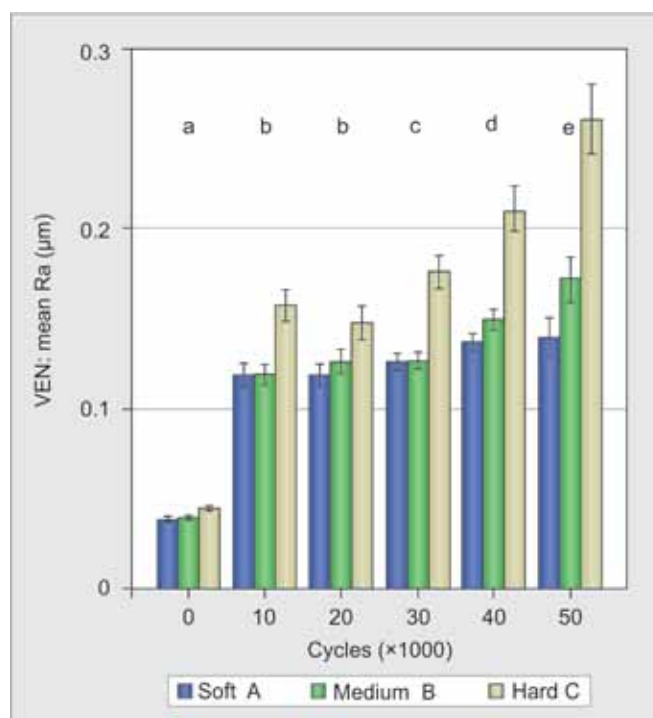

Fig. 4: Mean surface roughness Ra (μm) by cycles after brushing of VEN with abrasive slurry using soft, medium and hard toothbrushes, respectively. The t-shaped bars denote the 95% confidence intervals. Lower-case letters denote significantly different groups by brushing cycles in ascending order, whereas upper-case letters describe significant differences between the toothbrushes used in ascending order ($p < 0.05$)
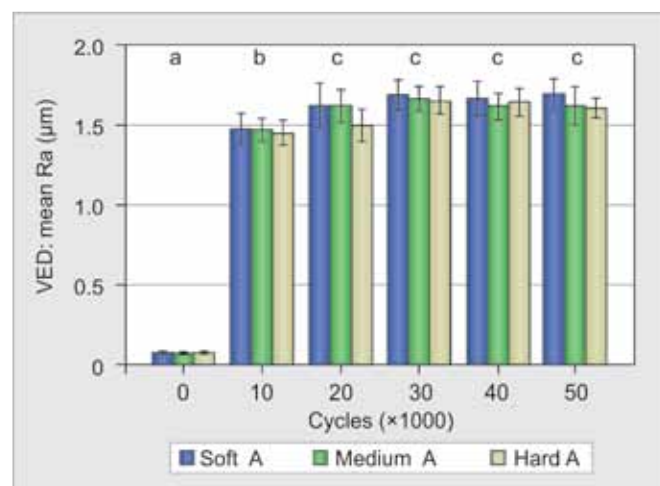

Fig. 5: Mean surface roughness Ra (μm) by cycles after brushing of VED with abrasive slurry using soft, medium and hard toothbrushes, respectively. The t-shaped bars denote the 95% confidence intervals. Lower-case letters denote significantly different groups by brushing cycles in ascending order. Toothbrush types showed no significant differences as indicated by upper-case letters ($p < 0.05$)
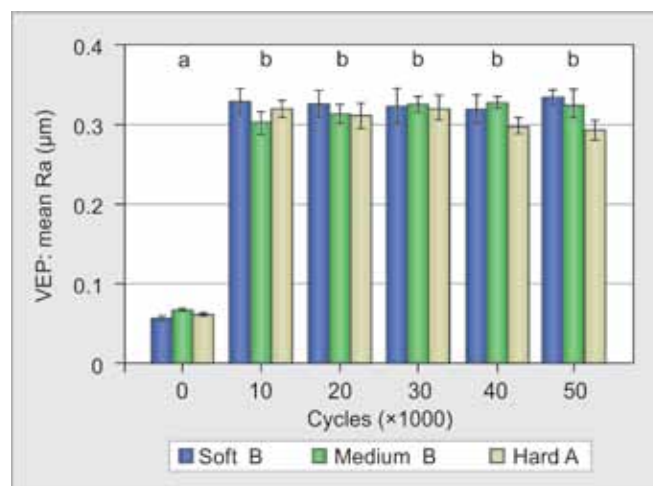

Fig. 6: Mean surface roughness Ra (μm) by cycles after brushing of VEP with abrasive slurry using soft, medium and hard toothbrushes, respectively. The t-shaped bars denote the 95% confidence intervals. The same lower-case letters describe that there were no significantly different groups by brushing cycles (10k through 50k), whereas upper-case letters show that there were no significant differences between soft and medium toothbrushes, yet less roughness produced by hard brushes ($p < 0.05$)

tested by number of brushing cycles with the toothpaste slurry. The box-and-whisker plots illustrate the median, the interquartile distance, and the minimum and maximum wear registered. The wear depth data of each material were subjected to univariate analysis and Tukey's post-hoc testing ($p < 0.05$). Lower-case letters above the groups denote in ascending order significant group differences by cycle number, whereas upper-case letters next to the toothbrush grade show significant differences, also in ascending orders, for the toothbrush used.

Table 2: Linear regression analyses: composite wear *vs* brushing cycles				
Composite resin	*Toothbrush type*	*Regression equation*	*R^2*	*Significance (p)*
Venus	Soft	y = 0.0034x + 3.80	0.998	<0.001
	Medium	y = 0.0031x + 13.16	0.998	<0.001
	Hard	y = 0.0032x + 15.86	0.998	<0.001
Venus Diamond	Soft	y = 0.0003x + 7.56	0.989	<0.001
	Medium	y = 0.0004x + 6.12	0.998	<0.001
	Hard	y = 0.0003x + 6.81	0.989	<0.001
Venus Pearl	Soft	y = 0.0014x + 4.18	0.999	<0.001
	Medium	y = 0.0015x − 0.02	0.999	<0.001
	Hard	y = 0.0016x + 2.82	0.998	<0.001

As demonstrated with the regression equations in Table 2, the wear data for each material/toothbrush combination were linearly correlated. All coefficients of determination (R^2) were highly significant.

Irrespective of the toothbrush grade used the maximum wear depths of VEN were highest, whereas the abrasion depths for VED were lowest.

The results of the surface roughness analyses for each material by toothbrush type are illustrated with the bar diagrams in Figures 4 to 6. The T-shaped signatures on top of the bars denote the 95% confidence intervals of the mean Ra values. As with the wear data above the surface roughness Ra of each material were subjected to univariate analysis and Tukey's post-hoc testing ($p < 0.05$). Lower-case letters above the groups denote in ascending order significant group differences by cycle number, whereas upper-case letters next to the toothbrush grade show significant differences, also in ascending orders, for the toothbrush grades used. The nonbrushed groups (0 cycles) give the roughness of the specimens ground on SiC paper #4000 prior to brushing.

The hybrid composite VEN exhibited the lowest surface roughness with Ra-figures between 0.1 and 0.3 μm, followed by nanohybrid VEP with average brushing roughness of Ra 0.3 μm and nanohybrid VED with very high Ra-figures of around 1.5 μm. The effect of the different toothbrush grades was significant for VEN, showing that the soft brush had produced significantly less roughness than the medium grade brush. Brushing with the hard toothbrush resulted in the significantly highest surface roughness. In case of VED the toothbrush grade used had no significant effect on surface hardness, whereas soft and medium type brushes produced significantly higher roughness on VEP specimens than hard brushes.

The surface textures of representative samples of the three composite resin materials after 50k toothbrush strokes are illustrated in the SEM pictures at 1000-fold magnification, shown in Figures 7 to 9. Morphologically, appearance of the VEN samples brushed with the different toothbrush grades is rather uniform. There is however a tendency of increasing filler dislodgement with increasing stiffness (hardness) of the toothbrushes used. The SEM photographs of the VED specimens show almost identical textures, irrespective of the toothbrush type. Large glass filler particles protrude from the composite surface; the polymer portion between these large fillers, showing much smaller fillers and a more uniform distribution, was deeply abraded. In contrast, the surfaces of VEP are rather uniformly worn. The comparatively large prepolymer particles are apparently abraded to the same level as the surrounding filler-loaded polymer. There are no signs of serious disintegration of the matrix or of filler debonding.
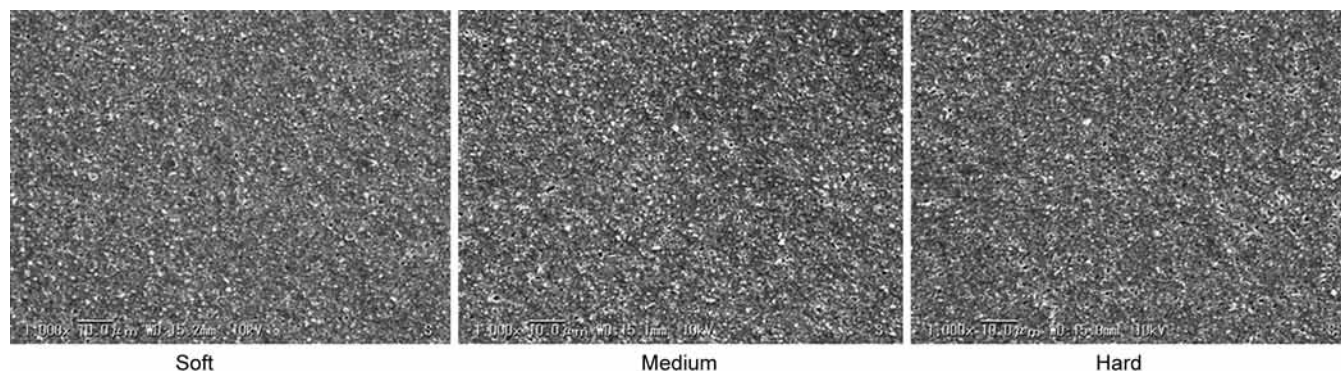

Soft   Medium   Hard

Fig. 7: The SEMs at 1k magnification demonstrate the surface textures of VEN specimens produced after 50k brushing with abrasive slurry for soft, medium and hard toothbrushes, respectively. With increasing hardness of the brush the number of pinhole defects left after filler exfoliation increases
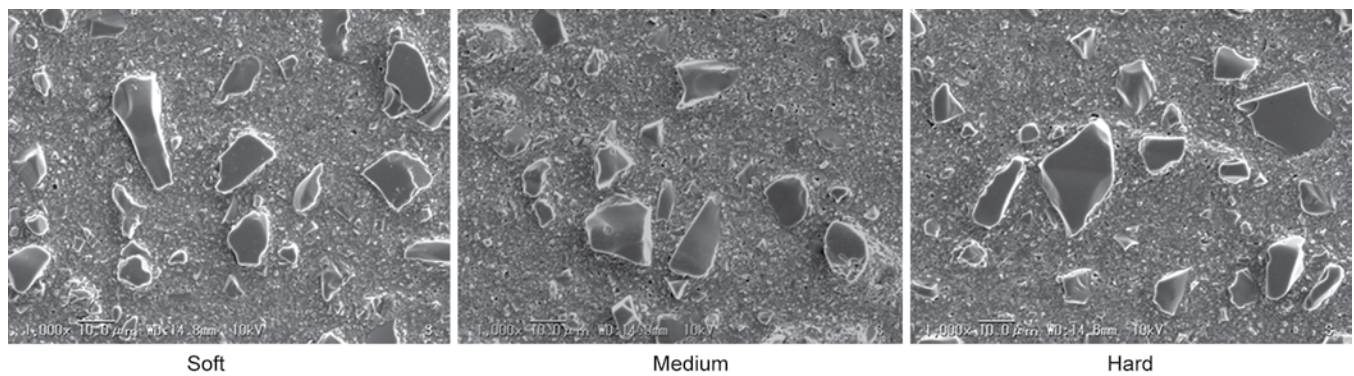
Fig. 8: The SEMs at 1k magnification demonstrate the surface textures of VED specimens produced after 50k brushing with abrasive slurry for soft, medium and hard toothbrushes, respectively. Large glass fillers protrude out of the surface; the matrix polymer loaded with smaller filler particles is selectively abraded
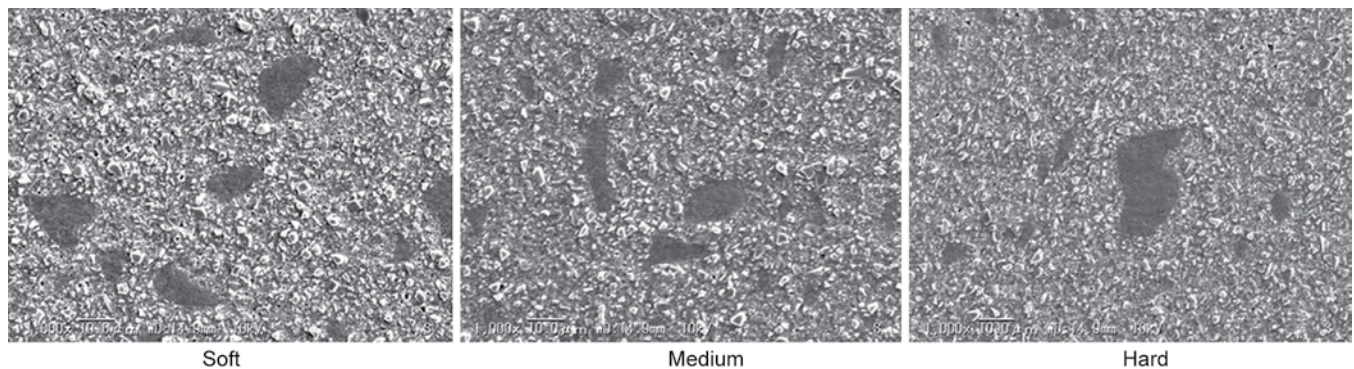

Fig. 9: The SEMs at 1k magnification demonstrate the surface textures of VEP specimens produced after 50k brushing with abrasive slurry for soft, medium and hard toothbrushes, respectively. The prepolymerized (black) filler particles and the surrounding matrix are very uniformly abraded

DISCUSSION

In the oral environment a variety of factors can adversely influence on free surfaces of composite resin restorations. Daily hygiene procedures are presumably among the important factors, especially on vestibular surfaces of restorations, whereas occlusal parts of the restorations are mainly affected by the interaction with opposing cusps and the food bolus. Toothbrushing may lead to roughening of surfaces and thus to enhanced retention of plaque and staining substances.[12] Although wide consensus exists that the toothbrush/toothpaste interaction is a determinant of surface roughness, so far no clearly defined critical threshold value for surface roughness of composite resins is defined. In contrast, on titanium implant abutments clinically a surface roughness Ra of 0.2 µm was found to be the borderline roughness for bacterial retention.[13,14] Whether or not the same threshold value holds for composite resin restorations is still a matter of debate.

The experimental conditions of the present investigation were adopted in order to simulate the clinical effects of toothbrush/dentifrice on composite restorations as closely as possible. Calcium carbonate slurry was chosen as the experimental toothpaste in order to avoid possible effects of nondeclared components of commercial toothpastes on composite wear. Further, calcium carbonate is due to the comparatively mild abrasive effect a frequently used abrasive in toothpastes recommended for daily use.[15]

In different laboratory trials widely differing loads on the toothbrushes are applied. In agreement with the load range specified in ISO/TR 14569-1 the load pressing the brush against the specimen was set to 2 N in the present trial.[16] This load is close to the average toothbrushing force of 3.3 N determined from 94 patients (range 1.4 through 7.2 N).[17]

Five times 10k brushing cycles were selected to make sure that even for products with very high wear resistance unequivocal abrasion values could be registered. According to previous reports 10k brushing cycles reflect approximately 1 year of toothbrushing.[18,19] Hence, the present trial would cover in total 5 years of toothbrushing.

For determination of the maximum depth of wear, among other methods described in literature the graphical determination of wear depth from profilometer traces, as used in the present investigation is a common and suitable procedure.[11]

The rationale for pregrinding all specimens on wet SiC paper grit 4000 was to establish a highly polished surface and to warrant comparable initial roughness for better assessment of the composites' intrinsic roughness.[11,20]

The null hypothesis tested in this study that the grade (stiffness) of the toothbrush used had no effect on wear, texture and roughness of the composite resin must be rejected. In terms of composite abrasion hard toothbrushes produced slightly higher wear than soft and medium brushes on VEN and on VEP, although the differences in wear related to the toothbrush grade are probably insignificant from a practical clinical viewpoint. Regarding surface roughness major differences caused by the different toothbrushes were only found for VEN, where in particular the hard brush created considerably higher roughness than the soft and the medium one. Generally, both wear and surface roughness were much more material dependent than related to the toothbrush. In agreement with a previous study the present findings proved that the composite wear resistance was not positively associated with lowered surface roughness.[21] SEM inspection of the textures of the worn composite samples suggested the following explanation for this apparent discrepancy. VEN showed rather uniformly and smoothly abraded surfaces, which is in agreement with the low surface roughness registered. However, the numbers of pinhole defects left after filler debonding was apparently increasing with increasing brush hardness when the composite was brushed with slurry, indicating that filler particles were continuously removed with increasing numbers of brushing cycles. A similar tendency, albeit less differentiated was shown for the depth of wear data with VEN. In contrast, VED showed very little wear, yet extremely high surface roughness. The scattered, irregular, large glass filler particles included in this product, measuring up to 20 µm, seem to support the tufted and deflected portion of the brush. Hence, the abrasive slurry is gradually driven over the filler-rich polymer phase between the protruding blocks where abrasion occurs. The large glass fillers are only moderately flattened/polished until, due to the continuous wear of the surrounding fine filler loaded matrix they lose their grip and are exfoliated. The maximum wear depth remains small even at large numbers of cycles whereas the surface roughness due to the size of the large protruding glass particles and the interparticle abrasion is very high. The SEM photographs of VEP demonstrate that exchange of the large glass filler fraction in VED with rather large prepolymer particles resulted in more uniform wear of the surface. In turn, the wear depth increased over the values recorded for VED and the surface roughness decreased to almost one-fifth of the VED roughness. Interestingly, the surface roughness for VED and VEP were almost unaffected by the number of brushing cycles.

Generally, when composite resins are brushed with toothpaste or toothpaste-like slurry protruding fillers are gradually removed. The result is increase in roughness. The freshly exposed polymer phase underneath offers less resistance to scratching and wears easily, predisposing for continued abrasion. Therefore, the composition of composite resins is an important determinant of wear, as filler size, shape, distribution, chemical link between filler and polymer, inter-particle distance, type of monomer as well as degree of conversion of double-bonds, all and in combination have an effect on the three-body-wear with toothpaste.

CONCLUSION

Within the limitations of this study the following conclusions can be drawn:

- Extent of abrasion and surface roughness of composite resins by toothbrushing with dentifrice (calcium carbonate slurry) depends mainly on the type of restorative resin used.
- Hardness grades of toothbrushes (stiffness of the tufted area) have minor effects on abrasion and surface roughness of composite resins.
- No relationship between abrasion and surface roughness of composite resins was detected.

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