Journal of Dental Sciences 18 (2023) 1016—1022

Available online at www.sciencedirect.com

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journal homepage: www.e-jds.com

Original Article

Surface roughness and gloss alteration of polished resin composites with various filler types after simulated toothbrush abrasion

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Received 18 November 2022; Final revision received 3 December 2022
Available online 15 December 2022

KEYWORDS
Surface roughness;
Gloss;
Resin composite;
Toothbrush abrasion

Abstract *Background/purpose:* Few studies have focused on the influence of simulated toothbrush abrasion on the surface qualities of novel nanofilled and nanohybrid composites. The aim of the study was to evaluate the surface roughness and gloss values of resin-based composite (RBC) materials with various filler types before and after simulated toothbrush abrasion.

Materials and methods: One nanofilled (Filtek Z350 XT [FT3]), two nanohybrids (Harmonize [HM] and Clearfil Majesty [CM]) and one microhybrid (Filtek Z250 [FT2]) were evaluated. Twelve specimens of each material were made and polished with silicon carbide sandpapers. Initial surface roughness and gloss values were measured as negative controls. Then, all specimens were subjected to simulated toothbrush abrasion on a custom-made apparatus. After 2000, 4000 and 8000 cycles, the surface roughness and gloss values of all specimens were tested. One additional specimen from each group was selected for scanning electron microscope (SEM) analysis.

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https://doi.org/10.1016/j.jds.2022.12.004

Results: For FT3, Ra and GU values did not significantly change until after 8000 cycles during the process of toothbrushing ($P > 0.05$). For HM, CM and FT2, the Ra and GU values significantly decreased after 4000 and 8000 cycles of toothbrush abrasion ($P < 0.05$). After 8000 cycles of toothbrush abrasion, FT3 presented the lowest surface roughness and highest gloss values of all materials ($P < 0.05$). SEM images showed that surface textures and irregularities corresponded to the results of surface roughness and gloss.
Conclusion: Surface roughness and gloss after simulated toothbrush abrasion were material dependent. Nanofilled resin composite presented the lowest Ra values and highest GU values.

Introduction

Surfaces of resin-based composite (RBC) restorations with unsatisfactory smoothness could lead to esthetic imperfection and dental plaque accumulation,[1] subsequently causing imperfection of the appearance as well as secondary caries alongside the margin of the restoration. Normally, surface quality is determined by restorative materials and finishing/polishing procedures.[2,3] With the development of dental biomaterials, various new RBC materials have been introduced for direct restoration due to their superior mechanical and surface properties, aesthetics and longevity. RBCs commonly consist of resin matrix and filler particles. Recently, nanosized filler particles have been widely used in the manufacture of RBCs to improve mechanical and clinical behaviors.[4] One of the improvements achieved by adding nanosized filler is surface smoothness.[5,6]

A definite classification of RBCs based on fill types is lacking. But it is well accepted that microhybrids contain filler particles with an average diameter of 0.6—1 μm and a proportion of 40 nm filler particles. And nanofilled RBCs contain none but nanofillers range from 1 nm to 100 nm. Then, nanohybrids is a combination of microhybrid and nanofilled-size particles.[7] On the market, nanofilled composites contained none but nanofillers and nanoclusters, while nanohybrid composites contain both nanofillers and hybrid fillers.[8] It has been proven that RBCs with nanosized fillers exhibit smoother surfaces after proper finishing and polishing. In our previous study, RBCs with nanosized fillers showed higher gloss values than microfilled RBCs.[9]

In concern of the RBC restored tooth in oral cavity, tooth brushing could be one of the most inevitable mechanical events, which may cause further abrasion, increase the surface roughness, and even accelerate the failure of the restoration over a long period of time. Previous studies demonstrated that the surface roughness of traditional RBC materials significantly increased after simulated toothbrush abrasion.[10—12] As new RBC materials put onto market with creative filler technology, limited literature has focused on the differences in surface qualities before and after tooth brushing between novel nanofilled and nanohybrid RBC materials.

Thus, the aim of the study was to evaluate the surface roughness and gloss values of nanofilled and nanohybrid RBC materials before and after simulated toothbrush abrasion. The null hypothesis was that RBC materials with different types of filler system did not have difference in surface roughness and gloss before and after simulated toothbrush abrasion.

Materials and methods

The materials used in this study contained a nanofilled resin composite (Filtek Z350 XT [FT3], 3 M ESPE, St. Paul, MN, USA), two nanohybrid resin composites (Harmonize [HM], Kerr, Orange, CA, USA) and (Clearfil Majesty [CM], Kuraray Noritake, Tokyo, Japan) and a conventional microhybrid resin composite (Filtek Z250 [FT2], 3 M ESPE). Detailed information was listed in Table 1.

Specimen preparation

Twelve disc-shaped specimens with 5 mm diameter and 2 mm thickness were made with a custom-made Teflon mold for each material group. Irradiation (BluePhase, Ivoclar Vivadent, Shaan, Liechtenstein) was applied from both sides for 20 s. The upper surface of all specimens was then polished with 600-, 1000-, 2000- and 5000-grit SiC abrasive paper in a grinder (AutoMet 250, Buehler, Lake Bluff, IL, USA). Polishing was performed for 60 s for each grit of abrasive paper under water cooling. All specimens were cleaned in an ultrasonic bath BioSonic UC100, Coltene Whaledent AG, Altstatten, Switzerland) with distilled water for 10 min. The specimens were then stored in distilled water at 37 °C for 24 h. Initial roughness and gloss measurements were made for each specimen.

Surface roughness measurement

The surface roughness of each specimen was measured using a surface profilometer (Surftest SJ-401, Mitutoyo, Kanagawa, Japan) with a stress force of 0.75 mN, standard cutoff of 1.0 mm, transverse length of 0.8 mm, amplitude height of 2.5 mm, and stylus speed of 0.5 mm/s. Two measurements of Ra were performed at cross directions for each specimen, and the numerical average of these values is reported.

Gloss measurement

Gloss was measured using a small-area glossmeter (Novo-Curve, Rhopoint Instrumentation, East Sussex, UK) with a

Table 1 Information of resin-based composites used in the study.

Material	Classification	Composition	Filler ratio (wt%/vol%)	Manufacture lot No.
Harmonize	Nanohybrid	**Resin:** BisGMA , BisEMA , TEGDMA **Filler:** nano-scale spherical silica and zirconia particles (5 nm), barium glass particles (400 nm)	81/64.5	Kerr 6,328,426
Filtek Z350 XT	Nanofilled	**Resin:** BisGMA, UDMA, TEGDMA, PEGDMA , BisEMA6 **Filler:** non-agglomerated/non-aggregated silica filler and zirconia filler (20 nm), and aggregated zirconia/silica cluster filler (0.6 −1.4 μm with primary particle size of 5−20 nm)	78.5/63.3	3 M ESPE N827944
Clearfil Majesty	Nanohybrid	**Resin:** BisGMA, Hydrophobic aliphatic dimethacrylate **Filler:** Silanated barium glass filler, Organic filler (0.2−100 μm, average 0.7 μm)	78/NA	Kuraray Noritake AR0027
Filtek Z250	Microhybrid	**Resin:** BisGMA, UDMA, BisEMA **Filler:** zirconia/silica (0.01 μm −3.5 μm with an average particle size of 0.6 μm)	82/60	3 M ESPE N659878

*BisGMA: bisphenol A glycidyl methacrylate; BisEMA: bisphenol-polyethylene glycol dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; UDMA: urethane dimethacrylate; PEGDMA: polyethylene glycol dimethacrylate.

square measurement area of 2 × 2 mm and 60° geometry. Gloss measurements were expressed in gloss units (GU). A custom-made, 10-mm-thick, black polytetrafluoroethylene mold was placed over the specimen during measurements to enable accurate specimen positioning and eliminate the influence of the overhead light.

Scanning electron microscope (SEM) analysis

One additional specimen from each group was selected for SEM analysis. The specimens were sputter coated with gold and observed with a scanning electron microscope (EVO 18; Zeiss, Wetzlar, Germany).

Toothbrush abrasion

After baseline roughness and gloss measurements, the testing surface of each specimen was then subjected to a toothbrush abrasion test. The toothbrushing apparatus was custom-made with dentifrice as the third body. It consisted of a water bath with 6 channels as reservoirs for third body abrasive. The specimen holder was placed on the bottom of each channel with the specimen testing surface upward. The specimens were immersed in a toothpaste slurry consisting of 50 g toothpaste (Max Clean ™, Colgate- Palmolive, New York, NY, USA) mixed with 100 mL of distilled water. Toothbrush heads (23 mm in length, 8 mm in width, medium hardness, 9.5 mm in filament length, Sanxiao, Guangzhou, China) were fastened in Teflon holders against the testing surface of the specimens. A weight of 300 g was placed on top of the holder. The bath was mounted on a reciprocating electric motor. Each cycle consisted of two straight 30 mm strokes on the center of the specimen holder. All specimens were subjected to 2000, 4000, and 8000 cycles. After every 1000 cycles the slurry was renewed. For each group, specimens were thoroughly cleaned of any treatment material residue both manually and in an ultrasonic bath with distilled water for 10 min to remove the eventual smear layer created on their surface. The surface roughness of each specimen was analyzed along three lines perpendicular to the brushing directions using the surface profilometer. Gloss measurements were subsequently made using the glossmeter as described above.

Statistical analysis

Statistical analysis was carried out using SPSS version 25.0 (IBM SPSS Inc., Chicago, IL, USA). Both Ra and GU data were found to be normally distributed after the Kolmogorov−Smirnov test. More than one group showed nonhomogeneity of variance after Levene's test. Therefore, nonparametric Friedman's test was applied as post hoc test to analyze the differences in Ra and GU values among baseline, 2000, 4000 and 8000 cycles of every material. The Kruskal−Wallis test was applied to analyze the difference in Ra and GU values among the four RBC materials. A *P* value less than 0.05 was considered statistically significant.

Results

Surface roughness

For CM and FT2, Ra values presented a significant increase after 2000, 4000 and 8000 cycles of toothbrush abrasion.

Table 2 Surface roughness Ra values of resin-based composites (μm).

Material	Baseline	2000 cycles	4000 cycles	8000 cycles
HM	0.045 ± 0.010^{Aa}	0.060 ± 0.018^{ACa}	0.081 ± 0.026^{Ab}	0.110 ± 0.021^{Ac}
FT3	0.048 ± 0.009^{Aa}	0.050 ± 0.019^{Aa}	0.051 ± 0.018^{Ba}	0.063 ± 0.017^{Bb}
CM	0.044 ± 0.009^{Aa}	0.100 ± 0.037^{Bb}	0.175 ± 0.059^{Cc}	0.172 ± 0.068^{Cc}
FT2	0.056 ± 0.015^{Aa}	0.071 ± 0.022^{Ca}	0.112 ± 0.037^{Db}	0.323 ± 0.090^{Dc}

*Different uppercase letters in each column indicate significant differences between materials ($P < 0.05$). Different lowercase letters in each row indicate significant differences at each toothbrush abrasion cycles ($P < 0.05$). HM (Harmonize), FT3 (Filtek Z350 XT), CM (Clearfil Majesty), FT2 (Filtek Z250).

Table 3 Gloss values of resin-based composites (GU).

Material	Baseline	2000 cycles	4000 cycles	8000 cycles
HM	90.2 ± 2.8^{Aa}	82.8 ± 3.2^{Ab}	75.1 ± 6.9^{Ac}	62.8 ± 5.3^{Ad}
FT3	94.0 ± 1.2^{Ba}	93.2 ± 1.8^{Ba}	89.8 ± 2.4^{Bb}	84.9 ± 2.3^{Bc}
CM	87.6 ± 1.2^{Ca}	67.9 ± 9.8^{Cb}	54.9 ± 10.6^{Cc}	34.4 ± 7.0^{Cd}
FT2	80.3 ± 1.3^{Da}	61.2 ± 4.4^{Db}	49.5 ± 11.6^{Cc}	31.3 ± 9.4^{Cd}

*Different uppercase letters in each column indicate significant differences between materials ($P < 0.05$). Different lowercase letters in each row indicate significant differ-ences at each toothbrush abrasion cycles ($P < 0.05$). HM (Harmonize), FT3 (Filtek Z350 XT), CM (Clearfil Majesty), FT2 (Filtek Z250).

For HM, Ra values increased after 4000 and 8000 cycles of toothbrush abrasion. For FT3, surface roughness did not significantly increase until after 8000 cycles of toothbrush abrasion. After polishing with sandpapers, the Ra values of all materials showed no difference. After 8000 cycles of toothbrush abrasion, FT2 presented the highest Ra values, and FT3 presented the lowest Ra values (Table 2).

Gloss value

For HM, CM and FT2, gloss values constantly presented a significant decrease after 2000, 4000 and 8000 cycles of toothbrush abrasion. For FT3, gloss values only started to decrease after 4000 cycles of toothbrush abrasion. Whether subjected to toothbrush abrasion or not, FT3 presented the highest gloss values. CM and FT2 presented the lowest gloss values after 4000 and 8000 cycles of toothbrush abrasion (Table 3).

SEM analysis

SEM images of all materials are presented in Figs. 1—4. Surface textures and irregularities corresponded to the results of surface roughness and gloss. After sequential polishing with sandpapers, all RBCs presented smooth surfaces with light scratches, and regular structures were clearly

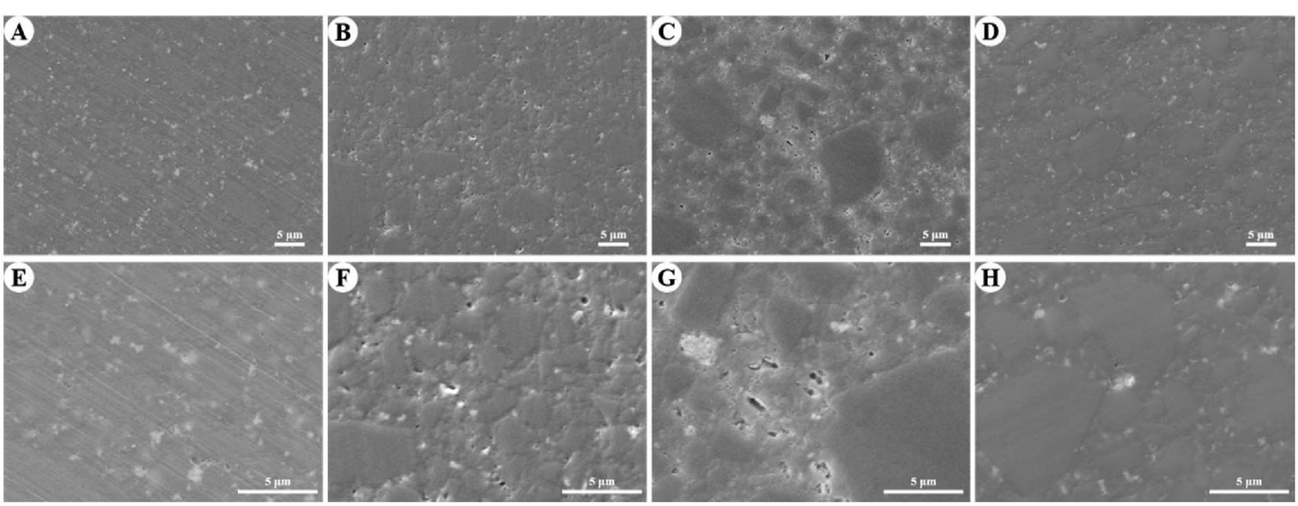

Figure 1 SEM images of HM (Harmonize). (A) baseline 2000 × ; (B) after 2000 cycles of toothbrush abrasion 2000 × ; (C) after 4000 cycles of toothbrush abrasion 2000 × ; (D) after 8000 cycles of toothbrush abrasion 2000 × ; (E) baseline 5000 × ; (F) after 2000 cycles of toothbrush abrasion 5000 × ; (G) after 4000 cycles of toothbrush abrasion 5000 × ; (H) after 8000 cycles of toothbrush abrasion 5000 × .

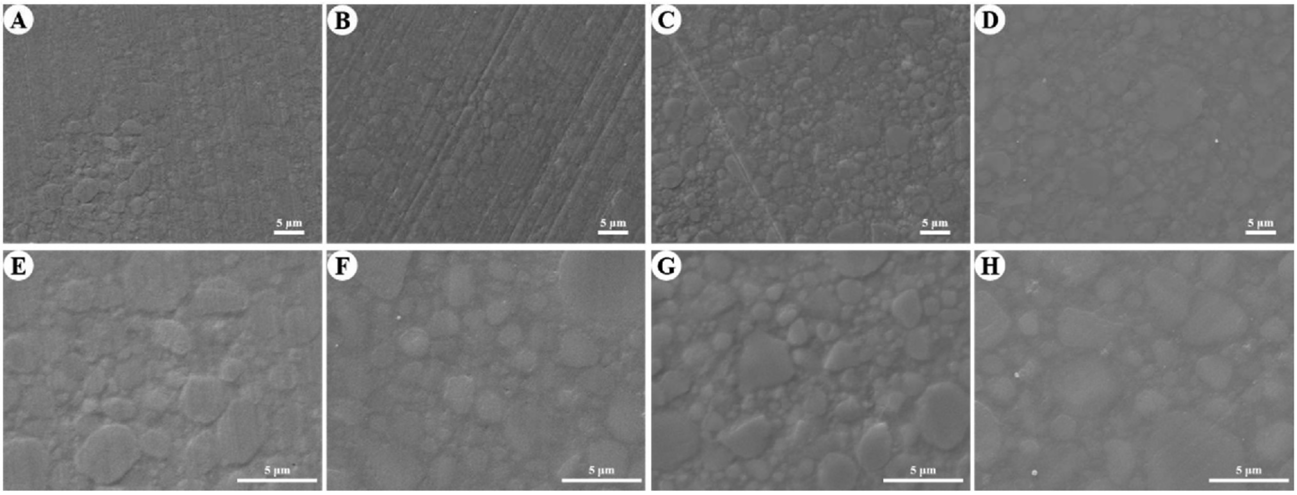

Figure 2 SEM images of FT3 (Filtek Z350 XT). (A) baseline 2000 × ; (B) after 2000 cycles of toothbrush abrasion 2000 × ; (C) after 4000 cycles of toothbrush abrasion 2000 × ; (D) after 8000 cycles of toothbrush abrasion 2000 × ; (E) baseline 5000 × ; (F) after 2000 cycles of toothbrush abrasion 5000 × ; (G) after 4000 cycles of toothbrush abrasion 5000 × ; (H) after 8000 cycles of toothbrush abrasion 5000 × .

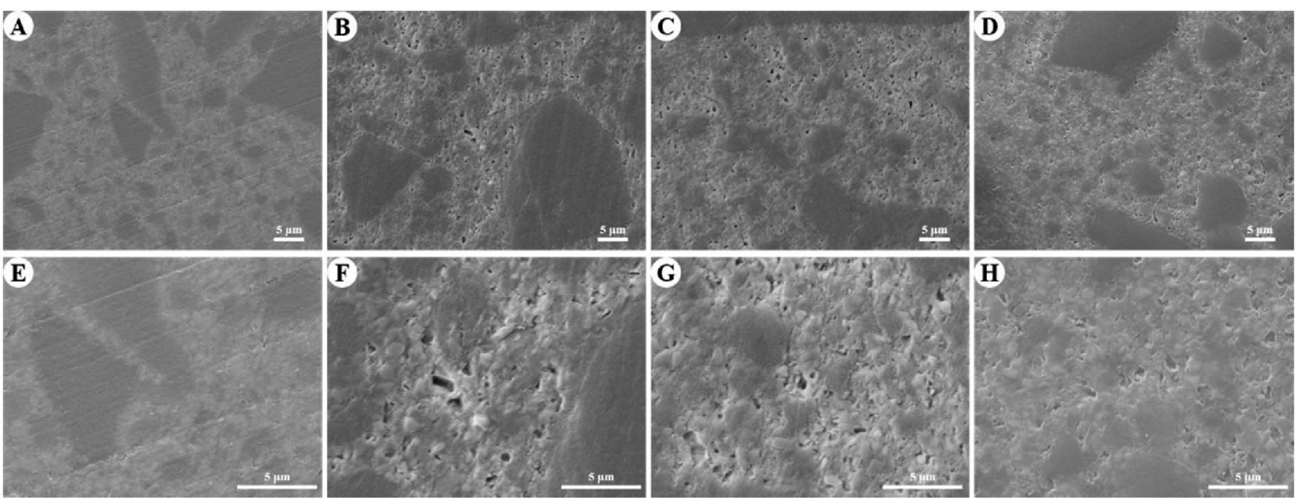

Figure 3 SEM images of CM (Clearfil Majesty). (A) baseline 2000 × ; (B) after 2000 cycles of toothbrush abrasion 2000 × ; (C) after 4000 cycles of toothbrush abrasion 2000 × ; (D) after 8000 cycles of toothbrush abrasion 2000 × ; (E) baseline 5000 × ; (F) after 2000 cycles of toothbrush abrasion 5000 × ; (G) after 4000 cycles of toothbrush abrasion 5000 × ; (H) after 8000 cycles of toothbrush abrasion 5000 × .

revealed. For HM, nanosized fillers were unevenly distributed. For the FT3 groups, spherical fillers and specific forms of nanoclusters could be observed. For the CM group, irregular fillers of various sizes could be detected. For the FT2 group, the outlines of filler particles were unclear.

After 2000 cycles of simulated toothbrush abrasion, for FT3, the amounts of scratches increased significantly, but no filler detachment was found. For HM, FT2 and CM, small pits caused by loss of filler particles were visible, while no obvious scratches or deep plows could be seen. The regular structures of all RBCs were still distinct.

After 4000 and 8000 cycles of simulated toothbrush abrasion, for FT3, only more scratches could be detected on the surface. For HM, CM and FT2, the amounts of pits apparently increased, and the fillers bulged outwards as the toothbrushing process went through. The basic structure of the surfaces became more ambiguous.

Discussion

This study examined the surface roughness and gloss of nanohybrid, nanofilled and microhybrid resin composite materials during the process of simulated toothbrush abrasion. Based on the results, the hypothesis was rejected.

Surface roughness is usually described by the parameter of Ra values. A profilometer could be used to test surface roughness. In our study, after polishing with sandpaper, two measurements of Ra were made at a cross direction for a better description of a flattened surface. In our study,

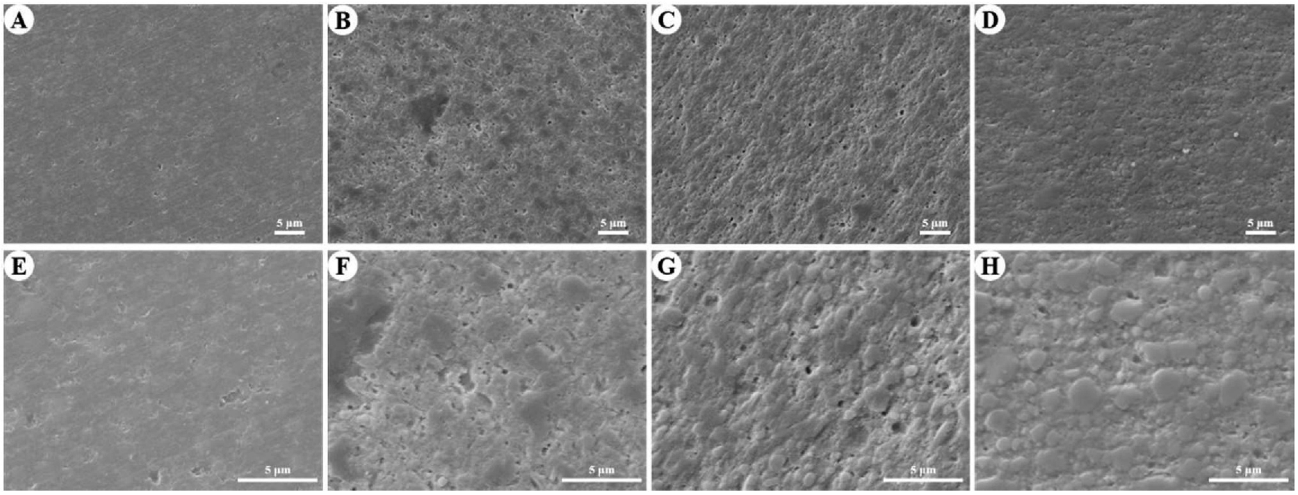

Figure 4 SEM images of FT2 (Filtek Z250). (A) baseline 2000 × ; (B) after 2000 cycles of toothbrush abrasion 2000 × ; (C) after 4000 cycles of toothbrush abrasion 2000 × ; (D) after 8000 cycles of toothbrush abrasion 2000 × ; (E) baseline 5000 × ; (F) after 2000 cycles of toothbrush abrasion 5000 × ; (G) after 4000 cycles of toothbrush abrasion 5000 × ; (H) after 8000 cycles of toothbrush abrasion 5000 × .

toothbrushing was simulated by a custom-made apparatus using a reciprocation mode in one direction. Therefore, after simulated toothbrush abrasion, Ra was measured perpendicular to the direction of toothbrushing to avoid smaller Ra measurements caused by the path of the stylus parallel to the scratches of the surface.

The gloss value is another parameter to examine the smoothness of surfaces, which is defined as the amount of light reflected by a surface at the same angle of the incident light.[13] Although Chiang et al. reported that surface glosses were strongly correlated with the subjective interpretation of surface texture,[14] they were also affected by filler size, load and filler distribution.[15] This could be explained by the high reflectivity of filler particles. In previous studies, RBC materials with smaller filler sizes presented higher surface gloss.[9,13]

Despite the aging of RBC materials after intraoral placement, toothbrushing is another essential factor that influences the long-term surface roughness and gloss, which may lead to esthetic failure of the restorations. Several studies have proven that surface roughness significantly increases after toothbrushing.[16,17] Jasse et al. reported a 60.2% reduction in gloss for RBC materials containing 75 wt % filler particles after simulated toothbrushing. In this study, we confirmed that toothbrushing could lead to increases in surface roughness and decreases in gloss values of microhybrid and nanohybrid RBCs such as HM, FT2 and CM. These results might be attributed to the composition of filler particles of the RBC materials. Both nanohybrid and microhybrid RBCs contain filler particles such as barium glass larger than 1 μm. In the process of toothbrush abrasion, it can be assumed that the wear rate of the resin matrix is faster than that of the filler particles and causes irregularity of the surface textures.[18] This could be proven by SEM images of HM, FT2 and CM, which showed that fillers bulging outwards formed an uneven pattern of surfaces.

For nanohybrid RBCs, it was noteworthy that the changes in Ra and GU values for HM were at a lower rate than those for CM. After abrasion, CM presented higher surface roughness than the other materials. This result was in accordance with Aytec et al.'s study, which showed that CM had a higher surface roughness than microfilled RBC FT2. This could be explained by the shapes and distribution of filler particles. Although CM was claimed a 'nanohybrid composite' by the manufacturer, it contains barium glass and prepolymerized organic fillers without any information on filler sizes. SEM showed that the filler shape of HM was spherical, while CM only contained irregularly shaped filler particles. In addition, nanosized fillers could be detected in HM, and no signs of nanosized fillers were observed in CM.

For nanofilled RBCs such as FT3, toothbrushing leads to mild changes in gloss values and surface roughness.[19] This might contribute to the specific filler pattern of nanoclusters. The agglomerates of zirconia/silica nanoparticles allow them to be worn off evenly and might not fall off and leave few pits on the superficial layer of the RBC material. In addition, filler particles should be situated as close as possible to protect the resin matrix from abrasives. Thus, nanofilled RBCs had lower surface roughness and higher gloss than nanohybrids due to the distribution of the filler interfaces after 8000 cycles of toothbrushing. This was also confirmed by SEM images of FT3, which presented few signs of surface defects.

In this study, we also found that the surface roughness of nanohybrid HM, CM and microhybrid FT2 nearly approached or exceeded the critical threshold of 0.2 μm after 8000 cycles of toothbrush abrasion.[20] As for gloss, CM and FT2 decreased to a level below the acceptable value of 53 GU, which equates to human enamel.[21] Previous studies proved that the gloss of human enamel did not degrade after simulated toothbrush abrasion.[22] Therefore, regardless of which types of RBCs are used for direct restoration, they cannot mimic the natural appearance of human teeth. According to the Bass method of toothbrushing, we could assume that the ideal toothbrushing process is 8 cycles per teeth 3 times a day, which means that 8000 cycles of simulated toothbrushing equate to a total brushing time of 1 year. Thus, according to this study, we recommended that nanohybrid and microhybrid RBC restorations be repolished at least once a year. For nanofilled RBC FT3, the repolishing time could be longer and needs to be further studied.

Under the limitations of the present study, it could be concluded that surface roughness and gloss after simulated toothbrush abrasion were material dependent. Nanofilled resin composite FT3 presented the lowest Ra values and highest GU values. During the toothbrushing process, the surface roughness of all groups significantly increased and gloss values of all groups significantly decreased.

Declaration of competing interest

The authors deny any conflicts of interest related to the present study.

Acknowledgements

This study was supported by Grant PKUSSNKP-202107 from Peking University School of Stomatology and the Chinese Stomatological Association Youth Founding (No. CSA-R2018-03).

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