Effect of tooth brushing on gloss retention and surface roughness of five bulk-fill resin composites

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Abstract

Objectives: To determine the effects of tooth brushing on five bulk-fill resin based composites (RBCs).

Method: Ten samples of Filtek Supreme Enamel (control), Filtek One Bulk Fill, Tetric EvoCeram Bulk Fill, SonicFill 2, SDR flow+, and Admira Fusion X-tra were light cured for 20 seconds using the Valo Grand curing light. After 24 hours storage in air at 37°C, specimens were brushed in a random order using Colgate OpticWhite dentifrice and a soft toothbrush. Surface gloss was measured prior to brushing, after 5,000, 10,000 and 15,000 back and forth brushing cycles. Surface roughness was measured after 15,000 brushing cycles using atomic force microscopy (AFM) and selected scanning electron microscope (SEM) images were taken. The data was examined using ANOVA and pair-wise comparisons using Scheffe’s post-hoc multiple comparison tests (α = 0.05).

Results: Surface gloss decreased and the surface roughness increased after brushing. Two-way ANOVA showed that both the RBC and the number of brushing cycles had a significant negative effect on the gloss. One-way ANOVA showed that the RBC had a significant effect on the roughness after 15,000 brushing cycles. For both gloss and roughness, brushing had the least effect on the nano-filled control and nano-filled bulk-fill RBC, and the greatest negative effect on Admira Fusion X-tra. The SEM images provided visual agreement. There was an excellent linear correlation ($R^2 = 0.98$) between the logarithm of the gloss and roughness.

Conclusion: After brushing, the bulk-fill RBCs were all rougher than the control nano-filled RBC. The nano-filled bulk-fill RBC was the least affected by brushing.

Clinical Significance

Bulk-fill RBCs lose their gloss faster and become rougher than the nanofilled conventional RBC, Filtek Supreme Ultra. The nanofilled bulk-fill RBC was the least affected by tooth brushing.

KEYWORDS

bulk fill resin based composites, gloss retention, operative dentistry

1 | INTRODUCTION

The combined outcomes of the 2013 Minamata agreement1 to phase down the use of dental amalgam and patient preferences for mercury free tooth colored restorations have meant that resin based composites (RBCs) are rapidly replacing dental amalgam as a restorative material.2 These RBC restorations are crosslinked polymeric materials that are reinforced using different sizes, shapes and types of filler particles. In
addition to displaying good physical properties, RBC restorations should be esthetically pleasing and smooth to reduce the accumulation of plaque. Consequently, the surface roughness after simulated masticatory and toothbrush wear is an important feature to consider when determining which RBC is best to use in a restoration.3–6 In a systematic review to determine if nanofill or submicron RBCs were smoother and retained their surface gloss after toothbrushing compared with micro-hybrid RBCs, it was reported that there was no good evidence to support the use of nanofill or submicron RBCs compared with micro-hybrid filled RBCs.7 However, this conclusion was based on three articles and one study included in the review did report that the nanofill RBC was better than two micro-hybrids.8 Orcomer® dental resins are hybrid polymer materials that have been synthesized by the sol-gel process and do not contain the classic monomers, such as BisGMA or TEGDMA, that are commonly used in dental resins (Table 1).9 The name Ormocer® is the acronym for organically modified ceramic and these products contain inorganic-organic co-polymers with an inorganic silanated filler particle. A solution and gelation process (sol–gel process) induces polymerization of multifunctional urethane and thioether oligo (meth)acrylate alkoxysilanes, to produce a silica glass by hydrolysis of the alkoxy groups.9 This process results in a matrix of long inorganic silica chains with organic lateral chains in the inorganic area of the polymer. The large size of the monomer molecule potentially reduces polymerization shrinkage, wear and leaching of monomers from the RBC.10

When compared with the initial baseline value, most RBCs show a significant degradation of surface roughness over time.10 Initially it was recommended that, because patients can discern surface scratches as small as 20 μm, the surface should have a maximum roughness of no more than 20 μm.11 Later studies have reported that patients can detect smaller differences in average roughness (Ra) values. The detection threshold ranged between 250 and 500 nm and it was concluded that restorations should have a maximum Ra of 500 nm.12 It is also known that more dental plaque and bacteria will form on rough surfaces compared with smooth surfaces.13–16 This increased accumulation of bacteria can then promote undesirable periodontal or carious sequelae.15 The maximum acceptable threshold for the surface roughness is ~200 nm after which the increased levels of bacterial plaque accumulation becomes a concern.4

The surface gloss is an attribute of visual appearance that is influenced by how light is reflected from the surface and is related to the surface roughness of the material.3 A glossmeter is used to measure the amount of light reflected off the specimen surface from an incident light beam and reports a numerical value on a scale of 1–100. Most gloss studies use a 60° angle of illumination7,8,17,18 and this angle is close to the angle the average person would observe the surface. A decrease in surface gloss is related to an increase in roughness,3,39 but the strength of the relationship has been questioned and may depend on the roughness value.17,18 In general, it has been reported that RBCs containing smaller filler particles show less reduction in gloss and less increase in surface roughness compared to those that contain larger irregular fillers,8 and RBCs that contain spherical fillers achieve the highest gloss after polishing.20

The gloss retention of different types of RBCs has been investigated in a variety of tooth brushing machines using a range of 500–50,000 brushing cycles.21–25 The ISO 11609:2010 standard for testing dentifrices uses 10,000 brushing cycles, one cycle being defined as a back and forth movement of the brush heads, over the specimens using a load of 150 g.26 It is estimated that between 10,000 and 14,600 back and forth brushing cycles in these machines corresponds to ~1 year of in vivo tooth brushing in a healthy individual.22,24,25,27,28

Bulk-fill RBC contains different types of filler and have different filler loading (Table 1). While physical properties, such as the polymerization shrinkage and the depth of cure of bulk-fill RBCs, have been extensively studied,29–33 the effect of tooth brushing these bulk-fill RBCs has yet to be studied. Whitening dentifrices have become popular with both manufacturers and patients alike. Whitening dentifrices often contain specific abrasives and chemical components such as hydrogen peroxide in their formulation that are designed to maximize cleaning power, remove stains, and whiten teeth.34 However, these cleaning agents are sometimes more abrasive than conventional dentifrices,22,34,37 and may negatively affect the gloss and increase the roughness and plaque retention on these RBC restorations.16 The American Dental Association (ADA) considers a relative dentine abrasivity (RDA) value of 250 as the maximum upper limit for dentifrices.35 Values below this upper limit are considered safe for a lifetime of use and clinical studies that have investigated dentifrices have not shown any significant difference in the amount of tooth wear when using dentifrices that have RDA levels below 250.35–37 According to the manufacturer, Colgate Optic White-Enamel White Toothpaste contains hydrogen peroxide that may affect restorations16 and its RDA abrasivity is 101. This RDA value is well within the maximum guidelines set by the ADA and since whitening dentifrices are widely used, they are a good choice to ascertain the effects of tooth brushing with a dentifrice on RBCs.

The purpose of this study was to determine the effect of tooth brushing on the surface gloss and roughness of five bulk-fill RBCs compared to a commonly used non-bulk-fill counterpart. The null hypotheses of this study were:

1. That there is no significant difference in the gloss retention among the tested bulk-fill RBCs.
2. That there is no significant difference in the surface roughness among the tested bulk-fill RBCs after 15,000 brushing cycles.
3. That there is no significant difference in the gloss retention between 5,000, 10,000 and 15,000 brushing cycles for any of the bulk-fill RBCs tested.
4. Surface gloss is unrelated to the surface roughness.

2 MATERIALS AND METHODS

Six brands of RBC were evaluated in this study. Table 1 lists the information provided by the manufacturers about the RBCs, and for the dentifrice used in this study. Five of the RBCs were intended for bulk filling and one was a conventional purely nanofilled RBC intended for incremental placement that acted as a control (Filtek Supreme Ultra Restorative shade A2 Enamel, 3M, St. Paul, USA). One product was a paste consistency purely nanofilled bulk-fill, Filtek One Restorative,
### TABLE 1  Manufacturer’s information about RBC and dentifrice

<table>
<thead>
<tr>
<th>RBC and (abbreviation)</th>
<th>Shade</th>
<th>Type</th>
<th>Lot number</th>
<th>Manufacturer</th>
<th>Matrix</th>
<th>Filler type and size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Admira Fusion X-tra (Fusion X-tra)</td>
<td>U</td>
<td>Bulk-Fill Nano-hybrid</td>
<td>1633453</td>
<td>Voco</td>
<td>Ormocer®®</td>
<td>Organically modified silicic acid</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Filler loading is 84.0% weight per weight. Silicon dioxide nanofillers (~20–50 nm) and silicon oxide-based hybrid fillers (~1 μm).</td>
</tr>
<tr>
<td>SDR flow+</td>
<td>A2</td>
<td>Bulk-Fill Nano-hybrid</td>
<td>1610081</td>
<td>Dentsply Sirona</td>
<td>Modified urethane dimethacrylate resin (SDR Resin), Bis-EMA, TEGDMA, TMPTMA</td>
<td>Filler loading is 70.5% by weight, 47.3% by volume. Barium-alumino-fluoro-borosilicate glass; Strontium alumino-fluoro-silicate glass; Surface treated fumed silica; YbF³ inorganic Particle size ranging from 20 nm to 10 μm.</td>
</tr>
<tr>
<td>SonicFill 2</td>
<td>A2</td>
<td>Bulk-Fill Nano-hybrid</td>
<td>6154931</td>
<td>Kerr</td>
<td>Dimethacrylates, BisGMA, Bis EMA</td>
<td>Filler loading 81.35% weight per weight. Silica, Barium glass, YbF³, mixed oxides. Particle size not stated.</td>
</tr>
<tr>
<td>Tetric EvoCeram Bulk Fill (Tetric Bulk Fill)</td>
<td>IVA</td>
<td>Bulk-Fill Nano-hybrid</td>
<td>T39247</td>
<td>Ivoclar Vivadent</td>
<td>Dimethacrylates, Bis-GMA, UDMA, Bis-EMA</td>
<td>Filler loading is 76–77% by weight, 53–54% by volume. Barium aluminum silicate glass with two different mean particle sizes, an &quot;Isofiller,&quot; ytterbium fluoride and spherical mixed oxide. The standard filler content is ~61% (vol.) plus 17% Isofillers cured dimethacrylates, glass filler and ytterbium fluoride. Particle sizes between 40 nm and 3 μm. The prepolymers include inorganic and organic products and are ~25 μm in size.</td>
</tr>
<tr>
<td>Filtek™ One Bulk Fill Restorative (One Bulk Fill)</td>
<td>A2</td>
<td>Bulk-Fill Solely Nano-filled</td>
<td>N782222</td>
<td>3M</td>
<td>Dimethacrylates, UDMA, AUDMA, DDMA, proprietary AFM</td>
<td>Filler loading is 76.5% by weight and 58.5% by volume. A combination of silane-treated nanoclusters and individual silane-treated nanosilica and nanozirconia. The nonagglomerated and nonaggregated silica filler is ~20 nm. The nonagglomerated/nonaggregated zirconia filler is ~4.11 nm, and the agglomerated ytterbium trifluoride (YbF³) is ~100 nm in size.</td>
</tr>
<tr>
<td>CONTROL Filtek™ Supreme Ultra Universal Restorative (Supreme Ultra)</td>
<td>A2E</td>
<td>Conventional Solely Nano-filled</td>
<td>N778771</td>
<td>3M</td>
<td>Dimethacrylates, Bis-GMA, UDMA, TEGDMA, Bis-EMA(6) resins</td>
<td>Filler loading is 78.5% by weight and 63.3% by volume. A combination of silane-treated nanoclusters and individual silane-treated nanosilica and nanozirconia. The nonagglomerated and nonaggregated silica filler is ~20 nm. The nonagglomerated/nonaggregated zirconia filler is ~4.11 nm in size.</td>
</tr>
</tbody>
</table>

Abbreviations: AUDMA, high-molecular-weight aromatic urethane dimethacrylate; DDMA, dodecanediol dimethacrylate; UDMA, urethane dimethacrylate; Bis-GMA: bis-phenol-A glycidyldimethacrylate; Bis-EMA, bisphenol-A-ethoxylated dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; TMPTMA, trimethylolpropane trimethacrylate. 

Data are provided by manufacturers.
(3M) that is claimed by the manufacturer to have superior esthetic properties. One, SonicFill 2 (Kerr Corp., West Collins, CA, USA), was a paste consistency nanohybrid bulk-fill that uses sonication to improve its flow properties. One, Tetric EvoCeram Bulk Fill (Ivoclar Vivadent, Schaan, Liechtenstein), was a paste consistency nanohybrid bulk-fill that claims improved esthetics and has a prepolymer shrinkage stress reliever. One of the paste consistency bulk-fill RBCs, Admira Fusion Xtra (Voca, Cuxhaven, Germany), is a nanohybrid Ormocer®. The fifth nanohybrid bulk-fill RBC, SDR flow+ (Dentsply Sirona, York, PA, USA), has a flowable consistency and is intended to be capped with a more wear resistant RBC.

In random order, the RBCs were packed into a 12.7 mm diameter, 2 mm deep split-mold with a Mylar sheet above and below. The SonicFill handpiece (Kerr) was set to 3 when dispensing SonicFill 2. A glass plate was placed above and below, and the RBC was pressed flat to achieve a smooth flat surface. The glass plate was removed and the specimen was light cured for 20 seconds through the top Mylar sheet using a broadband multivave LED dental curing light (Valo Grand, Ultradent Products, South Jordan, Utah, USA) set on the standard power output. This thickness of RBC and exposure time was well within the minimum values recommended by the manufacturers. The cured specimen was removed from the mold and excess material was removed by hand. All specimens were stored in air at 37°C for a minimum of 24 hours prior to testing, and, similar to some other studies, none of the surfaces were polished.

Tooth brushing was simulated using a custom made brushing unit (Ultradent) that can brush 10 specimens simultaneously, while applying the same predetermined load (Figure 1). The brushing unit moved the toothbrushes in a horizontal, back, and forth motion across the RBC surface, while the specimens also rotated. This ensured uniform brushing of the entire surface (see Supporting Information movie file). Soft bristled toothbrushes (GUM brand 495PC, Sunstar, Guelph, Ontario, Canada) with nylon filaments about 10 mm in length with all the ends lying in one plane were used. A constant load of 176 g, was used to provide ~2 N of force when brushing. This is a typical load used in other brushing studies and similar to the 150 g load used in the ISO standard.

After 10 specimens had been made for each RBC, they were randomly assigned to groups of ten to ensure there was no preferential treatment during brushing. The samples were covered with at least 3 mm whitening dentifrice slurry that was made using 25 g of each dentifrice (Colgate Optic White-Enamel White, Colgate-Palmolive, Toronto, Ontario, Canada) and 40 ml of water distilled water (a 5:8 ratio). In this machine, a brushing cycle is a back and forth stroke across the RBC at a frequency of 2 brush strokes per second for all experiments. The positions of each specimen in the brushing machine were rotated every 2,500 cycles (i.e., 5 times during the 15,000 brushing cycles to ensure equal brushing effects on the samples). Specimens were left inside the sample holders, washed, and dried to measure the gloss after 5,000, 10,000 and 15,000 brushing cycles. At the end, this number exceeded the number of cycles used in ISO 11609:2010 standard for testing dentifrices and represented an estimated 18 months of regular tooth brushing in a healthy person.

The gloss was measured using a glossmeter (Novo-Curve G, Rhopoint Instruments, Hastings, UK) that others have also used to measure the gloss of dental RBCs. Before each use, the glossmeter was calibrated using a traceable calibration tile (Rhopoint Instruments, South Jordan, Utah, USA) set on the standard power output. The gloss of each RBC and exposure time was well within the minimum values recommended by the manufacturers. The cured specimen was removed from the mold and excess material was removed by hand. All specimens were stored in air at 37°C for a minimum of 24 hours prior to testing, and, similar to some other studies, none of the surfaces were polished.

The surface roughness after 15,000 brush cycles and of the Rhopoint Instruments traceable calibration tile was measured using an AFM (nGauge, ICSPI Corporation, Rev 1.0, Waterloo, Ontario, Canada). The aluminum oxide tip, having a resonant frequency of 8–9 kHz, scanned the specimen at a rate of 250 μm/pixel (256 × 256 pixels) for a minimum of 2 scans per point. Three different points were measured on each specimen, each with dimensions of 25 by 25 μm. A 1.3 μm stage set (vertical) point was used and proportional and integration

**FIGURE 1** One side of a custom-built brushing unit that has a total of 10 brush holders, 5 on each side.
settings were adjusted to 5.0 and 5000, respectively. The data were analyzed using software (Gwyddion: http://gwyddion.net) to determine the average surface roughness (Ra), to obtain line profiles, and to produce 3D representations of the surfaces.

Representative samples were also examined using scanning electron microscopy at \( \times 5000 \) magnification (Hitachi S-4700 FEG, Toronto, Ontario, Canada) to visually compare surface roughness of the RBCs after 15,000 brush cycles. The samples were mounted and sputter coated with \( /C24 \) nm layer of gold-palladium. The scanning electron microscope (SEM) was operated at 3 kV and at a working distance of 12 mm.

### 3 | STATISTICAL ANALYSIS

Gloss data were examined by two-way ANOVA and roughness data by one way ANOVA. Pair-wise means comparisons were performed using the Scheffe’s post-hoc test. All statistical testing was performed at a pre-set alpha of 0.05.

### 4 | RESULTS

The means, standard deviations, and statistical analyses for surface gloss and roughness values are reported in Tables 2 and 3, respectively. The superscripts indicate which mean values are not statistically different (\( P > .05 \)). Figure 2 shows the means for gloss measurements prior to brushing and after 5,000, 10,000 and 15,000 brushing cycles. Two-way ANOVA showed that both the RBC and the number of brushing cycles had a significant negative effect on the gloss. Scheffe’s post-hoc multiple comparison tests showed that tooth brushing had the least effect on the control, Filtek Supreme Ultra Restorative A2 Enamel, where there was no statistical difference in the gloss value between 5,000, 10,000 and 15,000 brushing cycles. The nanofilled Filtek One Bulk Fill Restorative was the bulk-fill RBC that was least affected by brushing. This material had the same gloss value as the control RBC after 5,000 cycles, but not after 10,000 or 15,000 brushing cycles. In terms of gloss reduction, the trend continued from best to worst as follows: Filtek One Bulk Fill Restorative, Tetric Bulk Fill, SonicFill 2, and SDR flow

![Image](image-url)

The mean surface roughness values of all RBCs were significantly different, except between SDR flow+ and SonicFill 2 (Scheffe’s post-
hoc multiple comparison test $P > .05$). The results of the average roughness correspond to the gloss results, where high gloss (as in the Filtek Supreme Ultra Restorative and Filtek One Bulk Fill Restorative) resulted in low average surface roughness. Conversely, low gloss RBCs (e.g., Admira Fusion X-tra) result in a high average surface roughness. When the average roughness and average gloss for each RBC and the reference tile were plotted (Figure 4) on a semi-log scale between the logarithm of the average surface gloss ($x$-axis) and the average surface roughness ($y$-axis), there was an excellent, inverse, linear correlation ($R^2 = 0.98$).

The images presented in Figure 5 are three dimensional representations from the AFM scans of the RBCs after 15,000 brushing cycles. The images have all been scaled to match the scale of the roughest RBC. The

**FIGURE 2** Average gloss for each RBC, after 0, 5,000, 10,000 and 15,000 brushing cycles.

**FIGURE 3** Average surface roughness (Ra) with standard deviation measured by AFM, after 15,000 brushing cycles. Sample size = 10.
Surface of this brand of RBC had relatively large peaks and troughs, compared to either Filtek Supreme Ultra Restorative or Filtek One Bulk Fill Restorative, both of which appear to be flat in this figure. The same results are also visible in the 2-dimensional surface profiles from the AFM data shown in Figure 6, where again each RBC was plotted compared to the control RBC, and they are all on the same scale. The profiles of Admira Fusion X-tra and the control RBC are most different, whereas there is very little observable difference between the control RBC and Filtek One Bulk Fill Restorative. Supporting Information Figure S1 shows the images on their own individual scales, so that the surface can be more clearly seen. Figure 7 contains representative SEM images of the brushed RBC specimens after 15,000 brushing cycles at approximately the same imaging area as in the AFM images (~25 × 25 μm). Again, the Admira Fusion X-tra appears to have the roughest surface in these SEM images. This finding corroborates both the roughness and gloss results.

5 | DISCUSSION

The null hypotheses that there would be no significant difference in (1) the gloss retention or (2) the surface roughness among the bulk-fill RBCs were rejected. In all cases, the gloss decreased with the number of brushing cycles and the deleterious effect of brushing on the surface roughness varied among the different RBCs. Table 3 shows that the nanohybrid and the nanohybrid Ormocer® RBCs had significantly greater average roughness (Ra) values than both the purely nanofilled Filtek Supreme Ultra Restorative and Filtek One Bulk Fill Restorative (P < .05). Table 3 shows that after 15,000 brushing cycles, the bulk-fill RBCs were between 2 and 7 times rougher compared to the enamel shade of the conventional RBC. The results support a previous recommendation that manufacturers should inform consumers about the effects of dentifrices on dental restorations.22

The third null hypothesis was also rejected, because increasing the number of brushing cycles to 10,000 and then to 15,000 caused the gloss to progressively decline for Filtek One Bulk Fill Restorative, SonicFill 2 and SDR flow+. The mean gloss values for Admira Fusion X-tra were already very low (3.4–2.8) and were not significantly different. The fourth null hypothesis was rejected because there was a strong, inverse, linear relationship between the logarithm of the surface gloss and average surface roughness of the RBCs (R² = 0.98). Thus, for the range of roughness values observed in this study, it appears that surface gloss can be used to predict the average surface roughness of a RBC. This finding supports the results of Kakaboura et al.17 who reported that when the micro-roughness ranged from 30 to 140 nm there was a high correlation (r = 0.93) with gloss values, although when the Ra values ranged from 300 to 560 nm they reported that the correlation with gloss fell (r = 0.62).

Table 2 reports that there was no significant difference in the initial surface gloss of five of the RBCs, and only Admira Fusion X-tra was slightly, but significantly, different from Filtek One Bulk Fill Restorative. Ultimately, Admira Fusion X-tra was the least glossy and the roughest RBC after brushing. In this study, the surfaces were not prepolished, but instead the surfaces that had been directly photocured against the polyester Mylar strip were tested. This approach was chosen because the flowable SDR flow+ is not intended to be polished in the surfaces of the proximal box and the occlusal surface should always be covered.

![Graph showing the strong inverse linear relationship between average surface gloss and average surface roughness (Ra) of the different composites after 15,000 brushing cycles.](image1.png)

**FIGURE 4** Scatter plot showing the strong inverse linear relationship between average surface gloss and average surface roughness (Ra) of the different composites after 15,000 brushing cycles. Square data points are the different RBCs, and the triangle is the reference tile used to calibrate the glossmeter.

![Representative AFM scans of the brushed side of the RBCs [shade in square brackets], after 15,000 brushing cycles. The average roughness values ± standard deviation from the 10 repeats are also reported.](image2.png)

**FIGURE 5** Representative AFM scans of the brushed side of the RBCs [shade in square brackets], after 15,000 brushing cycles. The average roughness values ± standard deviation from the 10 repeats are also reported.
with a paste-like RBC. After polishing, few RBCs will achieve as smooth a surface that they initially had when photocured against a polyester Mylar strip and different polishing methods do not always achieve the same finish on all types of RBC.\textsuperscript{11,13,19,39–41} The initial surface that was polymerized against the Mylar would have been removed after a few hundred brushstrokes and thus it is the lack of any significant difference in the gloss values between the 5,000 and 15,000 brushing cycles for Filtek Supreme, Tetric EvoCeram Bulk Fill and Admira Fusion X-tra that is of clinical relevance, as it suggests that brushing has no further effect on the surface gloss or roughness once the initial layer of RBC is removed. Conversely, the continued decrease in the gloss values for Filtek One, SDR flow\textsuperscript{+}, and SonicFill 2 as the number of brushing cycles increase is of interest because this means that the surface of these RBCs continues to become rougher as the number of brushing cycles increases.

Of the six RBCs evaluated, the two purely nanofilled RBCs (Filtek One Bulk Fill Restorative and Filtek Supreme Ultra Restorative) displayed the highest gloss after 5,000, 10,000 and 15,000 brushing cycles.
cycles. These results were confirmed by the roughness values after 15,000 cycles, the surface profiles, and the SEM images (Figures 5–7). It was anticipated that the nanohybrid RBCs would do better.7 RBCs that contain both small and large particles, similar to the results from a previous study8 that looked at conventional RBCs, after mechanical brushing the nanohybrid RBCs bulk-fills, produced rougher surfaces than did the purely nanofilied RBCs. The nanofilied nature of the two Filtek nanofilied samples is visually apparent in the SEM images in Figure 7, where there is no evidence of any large particles on the surface of these two RBCs after brushing. In contrast, Figures 5 and 6 show the peaks and valleys present across the surface of the other RBCs after 15,000 brushing cycles. The Admira Fusion X-tra samples demonstrated the roughest surfaces, possibly due to the presence of clumps of the precondensed inorganic filler that were visible on the surface after the resin matrix had been brushed away.

AFM was used in this study because it has a greater capability to distinguish surface roughness compared to 2-D profilometry and it can reveal a more detailed definition of the surface than can SEM.17 Table 1 shows that the products evaluated in this study contained a variety of different resins, fillers, and percentage of filler content, all of which can affect how the RBC responds to wear.22,42,43 The nanohybrid RBCs contain a variety of particles with sizes ranging from 40 to 3,000 nm (3 μm), whereas the nanofilled RBC contains particles from 5 to 20 nm in size, that may be agglomerated into clusters that reach 600–1,400 nm in size. RBCs that contain purely spherical fillers reach the highest gloss after polishing,20 and the larger the size of filler particles,44 or the more irregular shaped the filler particles are,45 the rougher the surface becomes after polishing.41,46 or brushing.5 Thus, nanohybrid RBCs that contain a mixture of both nanoparticles and larger irregular shaped particles may have lower wear resistance, compared to those containing small and round-shaped particles that will also allow higher filler packing ratio.47,48 Figures 5 and 7 and the surface profiles shown in Figure 6 illustrate that the surface abrasion has removed the resin matrix in between the large filler particles in the nanohybrid RBCs. In some cases, the larger unsupported filler particles have been plucked out, leaving a particle-free resin layer that can then be easily and further abraded.49 In contrast, nanoclusters are intended to wear at the same rate as the surrounding resin matrix. As shown in the AFM images (Figure 5), the profile traces (Figure 6), and the SEM images (Figure 7), as each nanolayer or nanocluster is abraded away, a similar nanolayered surface is revealed below. There are no large particles to protrude or be plucked out of the resin layer, and thus the surface of a purely nanofilied RBCs remains smooth after brushing. This construction is thought to be the reason why the abrasion process is slower in purely nanofilied RBCs than for hybrid RBCs.21,50 In addition, the interface between the filler and the matrix is designed to chemically bond the matrix to the filler through a bifunctional organosilane.18,51 There may be differences between brands in how well this organosilane bonds the filler to the resin matrix. For some brands, this may be a weak link where microcracks can form and allow degradation of the RBC surface.52,53 If the RBC contains a prepolymerized filler, this is a potential weak link, because there are only a few residual double bonds on the surface of the prepolymerized filler. Thus, the bond between the prepolymerized filler particles to the resin matrix may be weaker than elsewhere and this may result in failure at this interface.

Since the gloss was visually different between the roughest and the smoothest RBCs after brushing, it brings esthetics and bacterial adhesion into question. The purely nanofilied RBCs had the least rough surfaces and it is likely that these RBCs, that are purely nanofilied, will feel smoother to the patient and attract less surface stain. This assumption is supported by an in vivo clinical report in the Dental Advisor, where 598 restorations were placed over a 6-year period. Of the 302 restorations that were evaluated on recall, it was reported that none were replaced due to lack of esthetics and often the restorations exhibited a very smooth and shiny surface texture.54 Rougher surfaces will accumulate more bacteria, which can lead to periodontal problems or future tooth decay and 200 nm has been suggested as the acceptable threshold for the surface roughness after which bacterial plaque accumulation becomes a concern.4 The mean surface roughness of Admira Fusion X-tra was 208 ± 31 nm after brushing, thus just exceeding this threshold. Mei et al. report that there is still bacterial accumulation even below this 200-nm limit and an average roughness value of 20 nm will collect less bacteria than a surface that has an average roughness of ~150 nm. After 15,000 brushing cycles, Table 3 shows that the bulk-fill RBCs with average Ra values between 57.7 and 208.2 nm were between 2 and 7 times rougher compared to the control conventional RBC (Ra 29.3 nm). Although these differences in the Ra values of any of these RBCs are unlikely to be detectable by the patient,11,12 they will likely collect more plaque than the conventional nanofilied RBC.

Given its excellent gloss retention and low roughness values after brushing, the enamel shade of Filtek Supreme Ultra Restorative would be a good choice for use in both anterior and posterior locations in the mouth, provided that the incremental filling technique is used. When looking at the five-tested bulk-fill RBCs, this study indicates that Filtek One Bulk Fill Restorative should retain the highest luster and be the smoothest RBC after tooth brushing. In addition, in view of the reduction in gloss and corresponding increase in roughness, this study supports the manufacturer’s recommendations that SDR flow+ should be covered with a paste consistency RBC.

This study examined the effects of tooth brushing on several contemporary bulk-fill RBC using the results from gloss retention, surface roughness, and selected SEM images. Although all three evaluation methods came to the same conclusions, a limitation of this study is the fact that the amount loss of surface material was not quantified. It is possible that the gloss and roughness of a material might be very acceptable, but the material may wear away faster than other products. Microfilled RBCs show more wear compared to microhybrid resins.38 However, purely nanofilied RBCs have less wear,21,50 and quantifying the extent of the wear was not the purpose of this study. It is recognized that the area directly below the polyester matrix may be more susceptible to surface degradation,55 but this initial surface would likely have been removed after a few hundred brush strokes, and this study examined the RBCs after 5,000, 10,000 and 15,000 brushing cycles. It has also been reported that there was no correlation between the surface roughness achieved after finishing and polishing procedures and
the final wear of the RBC.\textsuperscript{50} Gaining a better understanding of how surface roughness is affected by the filler, the resin matrix and the organosilane bond between the matrix and the filler could help in the selection of desirable toothbrushes or toothpastes. Assuming that a RBC restoration should last at least 10 years, it would also be valuable to look at longer brushing times and different toothpastes.

6 | CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions may be made:

1. As the number of tooth brushing cycles increased, the surface roughness increased and the gloss decreased for all RBCs.
2. The bulk-fill RBCs were between 2 and 7 times rougher compared to the enamel shade of the control RBC. The nanofilled bulk-fill RBC showed the least increase in roughness and smallest reduction in gloss after simulated tooth brushing ($P<.05$).
3. The RBCs nanohybrid fillers were more susceptible to the effects of tooth brushing compared to the RBCs that used only nanofillers (Filtek Supreme Ultra Restorative A2E and Filtek One Bulk Fill Restorative).
4. There is a strong, inverse, linear relationship between the logarithm of surface gloss and average surface roughness of the RBCs tested ($R^2 = 0.98$). Surface gloss could be used to predict the average surface roughness of a RBC when the Ra values are below 210 nm.

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