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In Vitro Evaluation of Surface Properties and Wear Resistance of Conventional and Bulk-fill Resin-based Composites After Brushing With a Dentifrice

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Clinical Relevance

Gloss retention, surface smoothness, and wear resistance are important factors when choosing resin-based composites.

SUMMARY

Objectives: This study evaluated the effect of toothbrushing with a dentifrice on gloss, roughness profile, surface roughness, and wear of conventional and bulk-fill resin-based composites.

Methods and Materials: Gloss and surface roughness of resin-based composites (RBCs; Admira Fusion X-tra, Aura Bulk Fill, Filtek Bulk Fill Flowable, Filtek Bulk Fill Posterior Restorative, Filtek Supreme Ultra, Herculite Ultra, Mosaic Enamel, SDR flow+, Sonic Fill 2, Tetric EvoFlow Bulk Fill and Tetric EvoCeram

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Bulk Fill) were analyzed before and after brushing; the roughness profile and wear were also determined after toothbrushing. Representative three-dimensional images of the surface loss and images comparing the unbrushed and brushed surfaces were also compared. Analysis of variance and Tukey post hoc tests were applied (α=0.05) to the gloss, surface roughness, roughness profile, and surface loss data. Pearson's correlation test was used to determine the correlation between gloss and surface roughness, surface loss and percentage of gloss decrease after brushing, and surface loss and surface roughness after brushing.

Results: For all RBCs tested after 20,000 brushing cycles, the gloss was reduced and the surface roughness increased ($p<0.05$). However, the roughness profile and the amount of surface loss were dependent on the RBC brand. Admira Fusion X-tra, Aura, Tetric EvoCeram Bulk Fill, and Tetric EvoFlow Bulk Fill showed the deepest areas of wear ($p<0.05$). A significant negative correlation was found between gloss and surface roughness, and a weak correlation was found between the decrease in gloss and the extent of surface loss, and any increase in surface roughness and the surface loss.

Conclusions: Toothbrushing with a dentifrice reduced the gloss, increased the surface roughness, and caused loss at the surface of all the RBCs tested. Considering all the properties tested, Mosaic Enamel exhibited excellent gloss retention and a low roughness profile and wear, while Admira Fusion X-tra exhibited the greatest decrease in gloss, the highest roughness profile, and the most wear.

INTRODUCTION

Resin-based composites (RBCs) have evolved significantly in terms of their use of filler content, resin matrix, and initiator systems.[1-3] These efforts have focused on improving the strength and wear resistance and decreasing the polymerization shrinkage stress of the RBCs. The features should enhance the clinical longevity of restorations, decrease the complexity of the restorative procedure, and decrease chairside time.[2,4,5]

Incremental filling and light curing have been used successfully for many years and are intended to both improve the margin adaptation and reduce the shrinkage stress after photocuring the RBC.[6,7] The introduction of bulk-fill RBCs has meant that instead of using the traditional 2-mm increment composite filling and curing technique, a 4- or 5-mm increment of bulk-filled RBC can now be successfully light cured.[4,8]

Bulk-fill composites have been classified according to their viscosity.[4] Low-viscosity bulk-fill composites (flowable composites) generally have a lower filler content and are best used as a base or for small restorations. High-viscosity bulk-fill RBCs generally have higher filler content and can be used to cover the softer flowable RBCs or they can be used to fill entire restorations because they have better wear resistance and improved mechanical properties compared with flowable RBCs.[4,9] Differences in filler content are also found within conventional RBCs, mostly with respect to particle size and shape. Smaller particle sizes will often produce RBCs that have greater surface gloss retention and improved wear resistance.[10,11] Besides the filler size and shape, the hardness of these fillers, the strength of the bond between the inorganic content and polymer matrix, and the light curing of the RBC can also affect the wear resistance.[12] Consequently, surface properties such as gloss, roughness, and wear resistance will vary among different RBCs. The surface gloss and smoothness of the composite surface are factors involved in the esthetic appearance of the restoration; glossier restorations may provide a better match to the surrounding tooth structure.[13] In addition, it has been reported that there is a significant relationship between the gloss and the surface roughness of RBCs.[13,14]

One of the main reasons for replacing an RBC restoration is the recurrence of tooth decay.[5] Surface roughness plays a crucial role in the amount of bacterial adhesion, biofilm accumulation, and surface staining.[15] Microbial colonization begins in the surface irregularities in which the bacteria can grow protected from the hydrodynamic shear forces and in which cleaning is also more difficult. This results in increased bacterial growth[16,17] and an increase in the risk of caries or periodontal disease.[18]

Therefore, it is clinically relevant to investigate the effect of toothbrushing with a dentifrice on the surface gloss, surface roughness, roughness profile, and the wear resistance of different commercially available RBCs. The null hypotheses of this study were as follows:

1. Toothbrushing would not affect the gloss retention of RBC specimens.

2. Toothbrushing would not affect the surface roughness of RBC specimens.
3. The roughness profile after brushing would not vary among different types of RBCs.
4. Surface wear after brushing would not vary among different types of RBCs.
5. There would be no correlation between the investigated properties.

METHODS AND MATERIALS

RBCs

To measure the effect of toothbrushing with a dentifrice on the change in gloss, surface roughness, roughness profile, and wear, a wide range of commercially available RBCs was chosen for this *in vitro* study. Table 1 describes the RBCs that were tested and their classifications. Sonic Fill 2 was delivered using two different sonication settings on the handpiece: 1 (slowest delivery) and 5 (fastest delivery).

Specimen Preparation and Brushing Cycling

A multiple-peak light-emitting diode light-curing unit (LCU; Valo Grand, Ultradent Products Inc, South Jordan, UT, USA; serial No. MFG3277-5) was used on the standard setting for 20 seconds to light cure all the RBCs. On this setting, the LCU delivered a radiant exitance of 953 mW/cm^2 and an emission spectrum from 380 nm to 490 nm, with three emission peaks (at 396, 447, and 466 nm). The output from the LCU was measured using a 6-inch integrating sphere (Labsphere, North Sutton, NH, USA) that was attached to a fiber-optic spectrometer (USB-4000, Ocean Optics, Dunedin, IL, USA). Five disks of each RBC were made on top of a Mylar strip in metal molds that were 2-mm thick and 12.7-mm in diameter. After the RBC was placed into the mold, it was covered with a Mylar strip and pressed flat with a glass plate, to obtain a flat and smooth surface. Then, the glass plate was removed, and the specimens were light cured, using the LCU that was held 2 mm away from the RBC surface. The Mylar strips were removed from the top and bottom surface of the RBCs after light curing, and the specimens were stored in the dark at 37°C. After 24 hours of storage, the initial gloss and roughness measurements were made. Adhesive tape (Scotch Commercial Vinyl Electrical Tape 700, 3M Electrical Markets Division, Austin, TX, USA) was then applied to only half of the top surface of the RBC disk to protect this area of RBC from brushing. This half of the specimen served as the control area (unbrushed RBC) for the wear measurements. The other half of each composite disk was brushed for 25,000 reciprocal strokes using an Ultradent brushing unit,[19] with a brushing speed of 2.5 cm/s. The toothbrushes moved horizontally, back and forth, while the sample holder rotated. It is considered that between 10,000 and 14,600 back-and-forth brushing cycles correspond to ~1 year of *in vivo* toothbrushing.[19] In this study, the 25,000 reciprocal strokes may be considered to be approximately 2 years of *in vivo* toothbrushing. Soft toothbrushes (Colgate 360° Soft, Colgate Oral Pharmaceuticals Inc, Toronto, Ontario, Canada) and a toothpaste (Colgate Optic White, Colgate Palmolive Canada Inc, lot No. 6150MX1134, RDA: 101) solution (50 g of toothpaste to 80 mL of deionized water) were used to brush the RBC disks with a 180-g force. This is a typical load used in other brushing studies and is similar to the 150-g load that is used in the ISO standard.[19-21] After brushing, the adhesive tape was removed, and the RBC disks were thoroughly washed and air dried.

Gloss Retention

The surface gloss (gloss units [GU]) was measured with the Novo-Curve glossmeter (Rhopoint Instruments Ltd, Hastings, Sussex, UK) at a 60° angle of illumination. The device has a 4.5-mm aperture and was calibrated (93.3 GU) with a plate provided by the manufacturer before the measurements. The first measurements (unbrushed) were made after 24 hours of storage and before the adhesive tape was applied to avoid any interference of the black adhesive tape on the gloss measurement. Similar to other studies, no finishing or polishing was done to compare the gloss achieved by each RBC against the Mylar surface.[19] After brushing, the brushed side could be visually detected by the loss of gloss. The brushed side of the disks was positioned over the aperture of the glossmeter. Three gloss measurements were made on each specimen before and after brushing, and an average of these three measurements was used. The results for each RBC were expressed in GU and analyzed using a two-way repeated-measures analysis of variance (ANOVA) that was followed by Tukey post hoc multiple-comparison tests (α=0.05).

Surface Roughness and Roughness Profile

After the gloss measurements, the surface roughness and roughness profile were measured using a confocal microscope (LEXT 3D Measuring Laser Microscope OLS4000, Olympus Corp, Tokyo, Japan) and OLS4000 software (Olympus Corp). A nonde-

Table 1: *RBC Manufacturer, Classification, Lot Number, and Shade*

RBC	Manufacturer (Address)	Type	Lot No.	Shade	Filler Loading, Type and Size
Admira Fusion X-tra	Voco GmbH (Cuxhaven, Germany)	Bulk-fill nanohybrid Ormocer	1604142	U	84.0% weight per weight. Silicon dioxide nanofillers (~20-50 nm) and silicon oxide–based hybrid fillers (~1 μm).
Aura Bulk Fill	SDI Limited (Bayswater, Victoria, Australia)	Full-body bulk-fill nanohybrid	160340	BKF	81 % by weight. Amorphous SiO_2, barium aluminosilicate glass, pre polimerized filler. Particle size not stated.[a]
Filtek Bulk Fill Flowable	3M ESPE (St Paul, MN, USA)	Flowable bulk-fill microhybrid		A2	64.5% by weight (42.5% by volume). Zirconia/silica particle size that ranges from 0.01-3.5 μ. The average particle size is 0.6 μ. The ytterbium trifluoride has a particle size range of 0.1-5.0 μ.
Filtek Bulk Fill Posterior	3M ESPE (St Paul, MN, USA)	Full-body bulk-fill nanofilled	N771662	A2	76.5% by weight (58.4% by volume). Non agglomerated/non aggregated 20-nm silica filler, a non agglomerated/non aggregated 4- to 11-nm zirconia filler, an aggregated zirconia/silica cluster filler (composed of 20-nm silica and 4- to 11-nm zirconia particles), and a ytterbium trifluoride filler consisting of agglomerate 100-nm particles.
Filtek Supreme Ultra	3M ESPE (St Paul, MN, USA)	Conventional nanofilled	N788069	A2 Body	78.5% by weight and 63.3% by volume. A combination of silane-treated nanoclusters and individual silane-treated nanosilica and nanozirconia. The non agglomerated and non aggregated silica filler is ~20 nm. The non agglomerated/non aggregated zirconia filler is ~4-11 nm in size.
Herculite Ultra	Kerr Corporation (Orange, CA, USA)	Conventional nanohybrid	6063375	A2 Enamel	78% by weight. Barium glass filler of 0.4 μm average size and silica nanofiller (20-50 nm).
Mosaic	Ultradent Products Inc. (South Jordan, UT, USA)	Conventional nanohybrid	BDZ19	Enamel	68% by volume for the dentin shades, and 56% for the enamel shades. Zirconia-silica glass ceramic and 20 nm silica.
SDR flow+	Dentsply Sirona (Milford, DE, USA)	Flowable bulk-fill nanohybrid	160910	A2	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.
Sonic Fill 2 (settings 1 and 5)	Kerr Corporation (Orange, CA, USA)	Bulk-fill nanohybrid		A2	81.35% weight per weight. Silica, barium glass, YbF3, mixed oxides. Particle size not stated.
Tetric EvoCeram Bulk Fill	Ivoclar Vivadent (Schaan, Liechtenstein)	Full-body bulk-fill nanohybrid	V23428	IVA	76%-77% by weight (53%-54% by volume). Barium aluminum silicate glass with two different mean particle sizes, an "Isofiller," 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.
Tetric EvoFlow Bulk Fill	Ivoclar Vivadent (Schaan, Liechtenstein)	Flowable bulk-fill microhybrid	V28277	IVA	68.2% by weight (46.4 by volume). Barium glass, ytterbium trifluoride, and copolymers (71 wt%). The particle size of the inorganic fillers ranges between 0.1 μm and 30 μm, with a mean particle size of 5 μm.

Data provided by the manufactures.
[a] *According to Karacolak and others (2017).*

structive three-dimensional analysis from a predetermined area of 6.76 mm^2 (2.6 × 2.6 mm) was made of the surface roughness. The roughness profile (two dimensions) was determined from the largest valley depth deviation from the mean line within a given length of 2.6 mm. Five measurements were made for each specimen, and the mean of these measurements was considered the roughness profile of that specimen. The surface roughness data were expressed in micrometers and were analyzed by two-way repeated-measures ANOVA followed by Tukey post hoc multiple-comparison tests (α=0.05). The roughness

Table 2: *Mean Gloss (±SD) of the RBCs Before and After Brushing*[a]

RBC	Unbrushed, GU	Brushed, GU	Mean Decrease of Gloss
Admira Fusion X-tra	81.6 (2.2) A d	2.9 (0.7) B f	96.4%
Aura	82.5 (3.3) A d	14.5 (1.4) B d	82.4%
Filtek Bulk Fill Flowable	94.5 (0.9) A a	28.7 (6.4) B c	69.7%
Filtek Bulk Fill Posterior	87.4 (3.3) A bcd	52.7 (5.3) B b	39.7%
Filtek Supreme Ultra	90.2 (2.2) A ab	69.8 (4.2) B a	22.6%
Herculite	89.3 (2.1) A abc	29.9 (0.9) B c	66.5%
Mosaic	90.6 (1.7) A ab	75.7 (2.5) B a	16.4%
SDR flow+	89.5 (2.1) A ab	11.8 (2.4) B de	86.8%
Sonic Fill (set:1)	90.8 (2.6) A ab	23.1 (2.6) B c	74.6%
Sonic Fill (set:5)	89.6 (3.1) A ab	26.5 (1.0) B c	70.4%
Tetric EvoCeram Bulk Fill	83.3 (3.0) A cd	13.3 (1.8) B d	84.0%
Tetric EvoFlow Bulk Fill	93.1 (1.9) A ab	7.1 (2.1) B ef	92.4%

[a] *Uppercase letters compare roughness between unbrushed and brushed surfaces within the same RBCs ($p<0.05$). Lowercase letters compare RBCs within the same composite surface (unbrushed or brushed; $p<0.05$).*

profile (in micrometers) was analyzed by one-way ANOVA and Tukey post hoc multiple-comparison tests (α=0.05).

Surface Loss (Wear) and Topographical Analysis

A noncontact optical profilometer (Proscan 2100, Scantron, Venture Way, Taunton, UK) with an S11/03 sensor that has a resolution of 0.012 μm was used to determine the surface wear caused by brushing. A 1-mm × 0.5-mm central area of the specimen that included both brushed and unbrushed surfaces was scanned for this analysis. A step size of 0.01 mm (number of steps: 100) was set for the x-axis, and a step size of 0.05 mm (number of steps: 10) was set for the y-axis. The depth of the brushed surface was assessed using the two-point height tool of the Proscan Application Software v.2.0.17, using the unbrushed surface as a reference. The mean height difference between the unbrushed and brushed areas of the specimen was calculated to obtain the surface loss. Data were exported to software (OriginPro 2017, OriginLab, Northampton, MA, USA), and representative images of the scanned surfaces were produced. The surface loss was expressed in micrometers and was analyzed using one-way ANOVA followed by Tukey post hoc multiple-comparison tests (α=0.05). Images of the specimen surfaces comparing the unbrushed and the brushed sides (1500×) were also obtained using a digital microscope (KH-1300, Hirox Co Ltd, Tokyo, Japan).

Correlation Coefficient

Pearson correlation tests (α=0.05) were used to identify if there was any correlation between gloss and surface roughness, surface loss and percentage of gloss decrease after brushing, and surface loss and surface roughness after brushing.

RESULTS

Gloss Retention

The mean gloss data before and after brushing and the mean percentage of gloss decrease are reported in Table 2. Before brushing, the initial gloss of the materials that had been light cured against the Mylar ranged from 81.6 GU (Admira Fusion X-tra) to 90.6 (Mosaic Enamel). After brushing, the gloss decreased for all the RBCs tested ($p<0.05$). The mean percentage of gloss decrease ranged from 96.4% (Admira Fusion X-tra) to 16.4% (Mosaic Enamel). Mosaic Enamel and Filtek Supreme Ultra showed the greatest gloss retention after brushing, with only a 16.4% and 22.6% decrease, respectively ($p<0.05$). There was no statistical difference between the specimens made on the two sonication settings (1 and 5) for Sonic Fill 2 ($p\geq0.05$).

Surface Roughness and Roughness Profile

Table 3 shows the mean surface roughness before and after brushing and the magnitude of the increase in surface roughness after brushing compared with the unbrushed side. Before brushing, the initial surface roughness ranged from 0.08 μm for Filtek Bulk Fill Flowable to 1.14 μm for Tetric EvoCeram Bulk Fill. After brushing, the surface roughness showed an increase for all RBCs ($p<0.05$), with values ranging from a low of 0.99 μm (Filtek Bulk Fill Flowable) to 2.67 μm (Filtek Bulk Fill Posterior). Filtek Bulk Fill Posterior showed the

Table 3: *Mean (±SD) Surface Roughness (Sa) of the Unbrushed and Brushed Surfaces of the RBCs*[a]

RBC	Unbrushed, μm	Brushed, μm	Times Increase of Sa
Admira Fusion X-tra	0.77 (0.32) A abc	2.05 (0.15) B bc	2.7
Aura	0.98 (0.55) A ab	1.67 (0.21) B c	1.7
Filtek Bulk Fill Flowable	0.08 (0.01) A e	0.99 (0.09) B e	12.4
Filtek Bulk Fill Posterior	0.56 (0.17) A bcde	2.67 (0.45) B a	4.8
Filtek Supreme Ultra	0.38 (0.09) A cde	2.36 (0.36) B ab	6.2
Herculite	0.59 (0.19) A bcd	1.68 (0.18) B c	2.8
Mosaic	0.15 (0.02) A de	1.14 (0.25) B de	7.6
SDR flow+	0.19 (0.04) A de	1.59 (0.07) B cd	8.4
Sonic Fill (set: 1)	0.42 (0.05) A cde	1.72 (0.10) B c	4.1
Sonic Fill (set: 5)	0.46 (0.15) A cde	1.67 (0.12) B c	3.6
Tetric EvoCeram Bulk Fill	1.14 (0.29) A a	2.20 (0.11) B ab	1.9
Tetric EvoFlow Bulk Fill	0.16 (0.02) A de	1.99 (0.15) B bc	12.4

[a] *Upper case letters compare roughness between unbrushed and brushed surfaces within the same RBCs (p<0.05). Lower case letters compare RBCs within the same composite surface (unbrushed or brushed) (p<0.05).*

greatest surface roughness after brushing, although it was not statistically different from the results for Filtek Supreme Ultra and Tetric EvoCeram Bulk Fill. On the other hand, Filtek Bulk Fill Flowable had the least surface roughness after brushing (although not statistically different from Mosaic Enamel). This was despite the fact that the surface roughness of Filtek Bulk Fill Flowable increased 12.4× after brushing. No statistical differences were observed in the roughness between the specimens made on the two different sonication settings (1 and 5) of Sonic Fill 2 either before or after brushing ($p \geq 0.05$).

The mean roughness profile data are reported in Table 4. Admira Fusion X-tra had the greatest roughness profile (3.38 μm), although this was not statistically different ($p \geq 0.05$) from Tetric EvoCeram Bulk Fill (2.84 μm), Filtek Bulk Fill Flowable (2.44 μm), and Aura (2.38 μm). Mosaic Enamel had the lowest roughness profile (0.92 μm), which was not statistically different from Filtek Bulk Fill Posterior (1.24 μm). There were no statistical differences observed between the specimens made using the two sonication settings (1 and 5) of Sonic Fill 2 ($p \geq 0.05$).

Table 4: *Mean (±SD) Roughness Profile (Rv) of the RBCs After Brushing*[a]

RBC	Rv, μm
Admira Fusion X-tra	3.38 (1.23) a
Aura	2.38 (0.33) ab
Filtek Bulk Fill Flowable	2.44 (0.45) ab
Filtek Bulk Fill Posterior	1.24 (0.12) cd
Filtek Supreme Ultra	1.99 (0.47) bc
Herculite	2.02 (0.27) bc
Mosaic	0.92 (0.14) d
SDR flow+	2.04 (0.19) bc
Sonic Fill (set: 1)	2.21 (0.31) bc
Sonic Fill (set: 5)	2.08 (0.23) bc
Tetric EvoCeram Bulk Fill	2.84 (0.48) ab
Tetric EvoFlow Bulk Fill	2.28 (0.31) b

[a] *Different letters indicate significant differences among RBCs (p<0.05).*

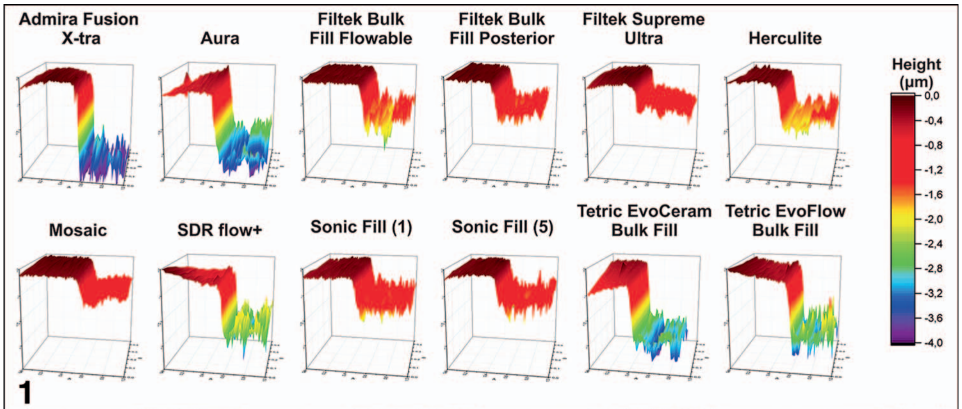
Surface Loss (Wear) and Topographical Analysis

The mean surface height loss values are reported in Table 5. Admira Fusion X-tra had the greatest surface loss (3.51 μm) compared with the other RBCs ($p<0.05$). The surface loss ranged from a low of 0.75 μm (Filtek Supreme Ultra) to 3.51 μm (Admira Fusion X-tra). No statistical differences were observed between specimens made using the

Table 5: *Mean (±SD) Loss in Height of the RBCs*[a]

RBC	Height Loss, μm
Admira Fusion X-tra	3.51 (0.55) a
Aura	2.33 (0.63) b
Filtek Bulk Fill Flowable	1.19 (0.18) ef
Filtek Bulk Fill Posterior	0.82 (0.18) f
Filtek Supreme Ultra	0.75 (0.14) f
Herculite	1.39 (0.19) def
Mosaic	0.88 (0.13) f
SDR flow+	1.97 (0.21) bcd
Sonic Fill (set: 1)	1.15 (0.13) ef
Sonic Fill (set: 5)	1.23 (0.09) ef
Tetric EvoCeram Bulk Fill	2.23 (0.36) bc
Tetric EvoFlow Bulk Fill	1.56 (0.31) cde

[a] *Different letters indicate significant differences among the RBCs (p<0.05).*



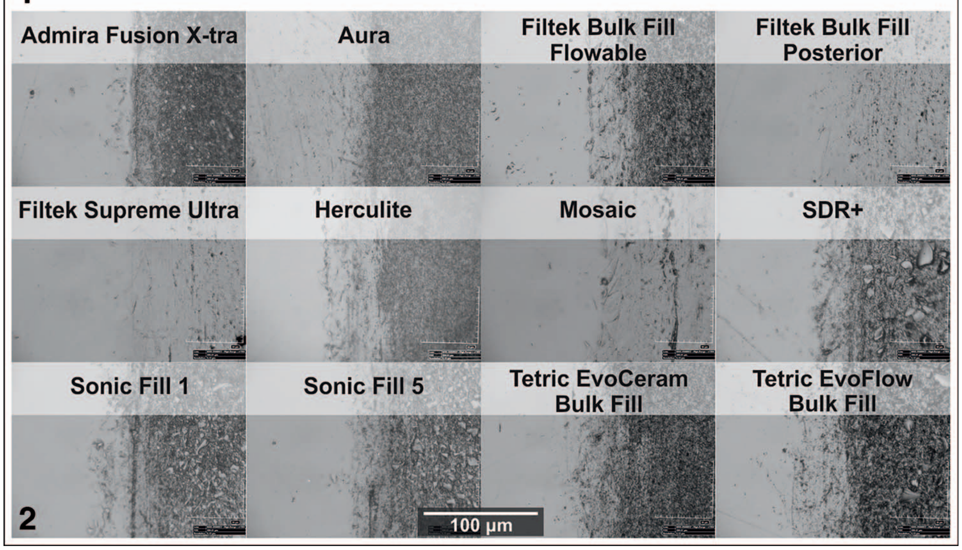


Figure 1. *Loss in surface height (µm) of the RBCs, comparing the nonbrushed (reference surfaces) and the surfaces after brushing.*

Figure 2. *Surfaces of the RBCs before (left side) and after (right side) brushing.*

two sonication settings (1 and 5) of Sonic Fill 2 ($p \geq 0.05$). Figures 1 and 2 are representative images of the values described in Table 5 and Table 3, respectively. In Figure 1, the deepest areas, represented by the dark blue and purple colors, were observed in Admira Fusion X-tra, Aura, Tetric EvoCeram Bulk Fill, and Tetric EvoFlow Bulk Fill (Figure 1). Figure 2 shows representative microscopy images of all the RBCs on the unbrushed (left) and the brushed sides (right). After brushing, the filler particles of some RBCs were exposed, which can be seen in the images of Admira Fusion X-tra, SDR+, Sonic Fill 2, and Tetric EvoFlow Bulk Fill. The image of SDR flow+ after brushing shows filler particles that were greater than 10 µm in size.

Correlation Coefficient

Figure 3 shows that the decrease in gloss after the toothbrushing for most of the samples tested was correlated with the increase in surface roughness (inverse linear correlation, $p<0.05$; $R^2=0.5504$). Figure 4 shows the positive correlation ($p<0.05$; $R^2 = 0.4617$) between the percentage of gloss decrease and the surface loss (wear of the material). Figure 5 shows that there was a weak interaction between surface roughness and surface loss ($p<0.05$; $R^2=0.0802$).

DISCUSSION

RBCs have become the material of choice for direct restorations and are widely used in dental practice.[5] Clinically, maintaining a smooth surface on the RBC is important because it may reduce plaque retention, surface discoloration, tissue inflammation, and secondary caries; improve the esthetics; and potentially add to patient comfort.[22,23]

In this study, toothbrushing with a dentifrice decreased the surface gloss and increased the surface roughness for all tested RBCs, thus rejecting both the first and the second null hypotheses. The differences in roughness profile and wear after brushing among the RBCs meant that the third and fourth null hypotheses were also rejected.

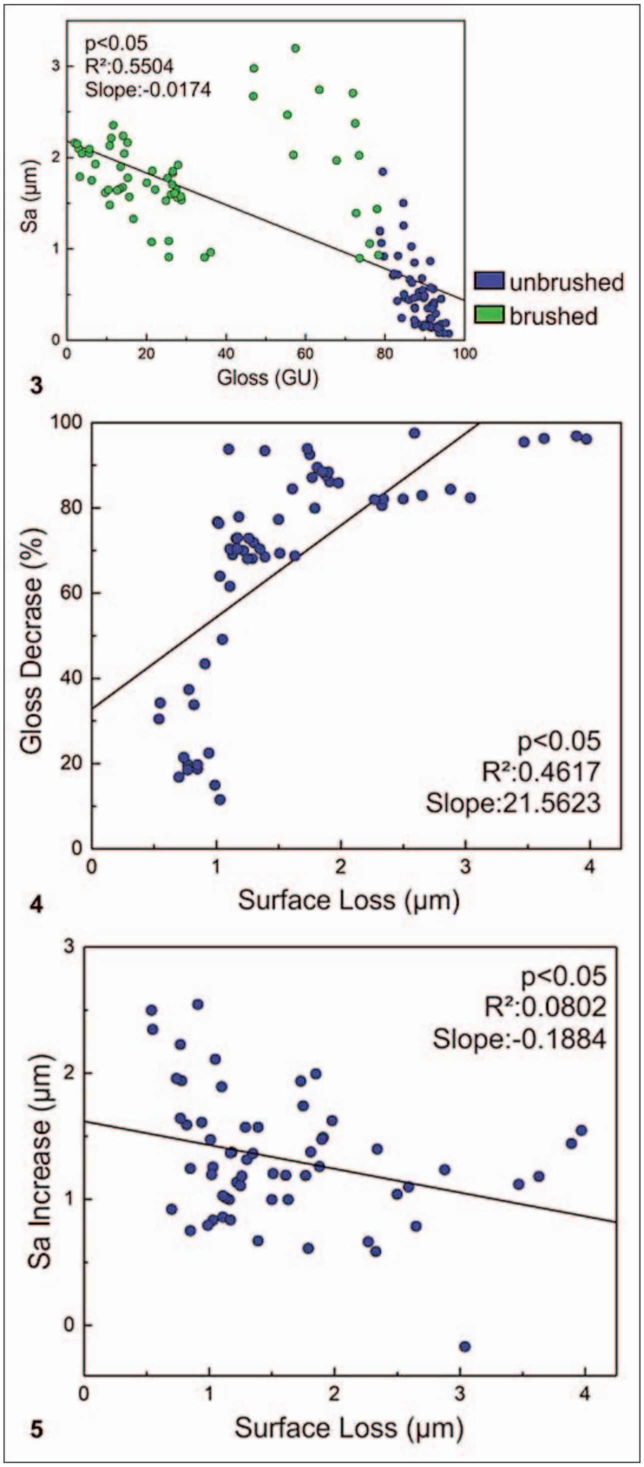


Figure 3. *Scatter graph showing a moderate negative correlation between RBC surface roughness (Sa) and gloss (GU) for unbrushed and brushed side (p and R^2 values, Pearson correlation test).*

Figure 4. *Scatter graph showing a positive correlation between RBC surface gloss decrease and surface loss after brushing (p and R^2 values, the Pearson correlation test).*

Figure 5. *Scatter graph showing a weak negative correlation between RBCs surface roughness (Sa) and surface loss (µm).*

Among many factors, the gloss can be affected by the particle size, chemical heterogeneity, and surface defects in the RBC.[22,24] Two of the RBCs tested, Admira Fusion X-tra (a nanohybrid Ormocer, organically modified ceramics) and Tetric EvoFlow Bulk Fill (a flowable bulk-fill composite), had more than a 90% decrease in gloss. The manufacturer recommends that Admira Fusion X-tra be used for class I, II, and V restorations and not in esthetic areas such as class III and IV, where the loss in gloss would be more important to the patient. Mosaic Enamel exhibited the greatest gloss retention (16.4% gloss decrease) followed by Filtek Supreme Ultra (22.6% gloss decrease); these RBCs are conventional nanohybrid and nanofilled composites, respectively. Herculite Ultra, also a conventional composite, had low gloss retention (66.5% gloss decrease). This RBC includes nanohybrid filler particles and was expected to have better gloss retention due to the spherical-shaped filler particles.[23] However, since the gloss decreased after 2 years of simulated toothbrushing, restorations may require repolishing or even replacement, to meet the esthetic requirements of the patient.[25]

It is claimed that the larger size of the monomer molecules used in the Ormocer would reduce polymerization shrinkage and wear and leach fewer monomers.[26] However, this RBC exhibited the greatest surface loss, a large increase in surface roughness, a rough surface profile after brushing, as well as a large decrease in surface gloss. Another study has also reported low gloss retention and an increase in surface roughness for Admira Fusion X-tra, even after only 5000 reciprocal strokes.[19]

Some studies report that the surface roughness of composites is a key factor in biofilm formation,[17,27] and this increases the risk of caries around dental restorations.[28] Conversely, other studies have failed to report any significant relationship between the surface roughness and an increased biofilm formation.[16] However, this result may be due to the difficulty in standardizing the polishing procedure[28] or by the prolonged bacterial incubation that was used in the study, in which new bacteria adhered to the biofilm and not to the surface of the RBC that was being tested.[17] Another study showed that the surface topography might be considered more important for *Streptococcus mutans* biofilm formation than surface roughness, and according to the same authors, deeper and larger depressions may provide a more favorable region for bacterial colonization and biofilm formation because bacterial colonies are more difficult to remove from a rough surface.[28] In the present study, the topography was analyzed both by the surface roughness and by the roughness profile. Considering the surface topography of the different specimens, it is suggested that there will be increased and more mature biofilm formation around brushed Admira Fusion X-tra, Aura, Tetric EvoCeram Bulk Fill, and Tetric EvoFlow Bulk Fill RBCs. However, further investigations regarding the formation of biofilm after brushing are required as many other factors such as the chemical composition and the surface free energy of the RBC may affect biofilm formation.[17]

Previous studies have considered that bacterial adhesion should not occur below a profile roughness threshold of 0.2 μm.[29] According to this threshold, bacterial adhesion would be increased for all tested RBCs after toothbrushing (Table 3). However, this threshold was based on a profile roughness instead of the surface roughness measurement that was used in the present study. Also, a recent systematic review identified that a threshold could not reliably predict the bacterial adhesion.[30] This may make the comparison of the results of the present studies and this threshold unfeasible.

The roughness that patients could theoretically detect was also studied using a previously established profile roughness threshold of 0.5 μm.[31] All RBCs tested would present a roughness increase of more than this value after the simulated 2-year toothbrushing (Table 3), which may lead to the necessity of repolishing restorations, but again, this threshold was also reported in profile roughness and not surface roughness.

Although some flowable bulk-fill composites such as Filtek Bulk Fill Flowable can be placed in small posterior occlusal restorations, other flowable bulk-fill composites, such as SDR or Tetric EvoFlow Bulk Fill, are not recommended by the manufacturers to be placed in areas of occlusal loading, where a covering layer of a more wear-resistant RBCS is required.[4] More wear was expected for all the flowable bulk-fill composites, but this was not always the case. Instead, the flowable RBCs displayed intermediate results or even low results, such as those seen in Filtek Bulk Fill Flowable. However, this study evaluated only the wear of RBCs after toothbrushing, and the effect of the occlusal loading on these materials was not tested. Of the high-viscosity bulk-fill composites, Filtek Bulk-Fill posterior maintained the greatest gloss retention (39.7% of gloss decrease) and the least wear after toothbrushing.

Although the wear resistance may depend on the degree of conversion of the monomers,[33] these RBCs were well cured and stored for 24 hours before testing. It is expected that RBCs that have a lower filler loading may have greater wear because the resin matrix is less protected by the fillers and will be more readily removed.[32,33] However, Admira Fusion X-tra and Aura had greater wear, even though both were nanohybrid composites with 84% and 81% of filler loading, respectively. There was less wear on Filtek Bulk Fill Posterior, Filtek Supreme Ultra (nanofilled), and Mosaic Enamel (nanohybrid). Figures 1 and 2 also show a flatter surface for these RBCs compared with the other RBCs that were tested. Thus, the gloss retention and wear results reported in this study corroborate the theory that RBCs may differ after brushing due to the quality of silanization of the organic matrix,[13] as the gloss decrease or the amount of surface loss could not be predicted from the percentage filler loading.

The fifth null hypothesis was also rejected because a significant inverse correlation between gloss and surface roughness was observed. Other authors have also observed a similar inverse linear correlation between gloss and surface roughness after toothbrushing.[19,34] This occurs because the rougher the material, the more light is scattered on its surface, leading to a decrease in the gloss.[14] Also, a positive correlation between gloss decrease and surface loss and a negative correlation between surface roughness and surface loss was observed. However, these correlations were weak (R^2=0.46 and 0.08). This observation may be explained by the difference in the reflective index of the exposed filler particles, reducing the gloss retention relative to the wear of the resin composites. The whitening toothpaste used in the study had an RDA of 101 and can be considered to have a medium abrasiveness. This RDA can be compared with the abrasiveness of some prophylactic polishing pastes.[35] Thus, after an initial surface roughness increase, the toothbrushing may have caused some polishing of the surface of the RBCs, leading to a weak positive correlation between gloss decrease and surface loss and a weak negative correlation between surface roughness and surface loss.

The excellent results for Mosaic Enamel suggest this material can be successfully used for RBC restorations, with regard to the wear expected from toothbrushing. Also, regarding anterior esthetic restorations requirements, this material retained a high gloss value. Most of the high-viscosity bulk-fill RBCs achieved properties comparable with those of conventional RBCs, except for Admira fusion X-tra, which was the most affected by toothbrushing. No difference between the sonication settings were observed for Sonic Fill 2 regarding the properties tested; however, further physical and mechanical properties should be studied to determine the best sonication setting.

CONCLUSIONS

Within the limitations of the current study, the following conclusions can be made:

1. Toothbrushing with a dentifrice reduced the gloss, increased the surface roughness, and caused surface loss for all RBCs tested.
2. There was a negative correlation between gloss and surface roughness.
3. Considering all the tested properties, Mosaic Enamel displayed excellent gloss retention, low surface profile roughness, and low wear; in contrast, Admira Fusion X-tra was the most affected by toothbrushing, exhibiting the greatest decrease in gloss, the greatest roughness, and the most wear.
4. The properties tested were product and not type dependent.

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Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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