Toothbrushing alters the surface roughness and gloss of composite resin CAD/CAM blocks

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This study investigated the surface roughness and gloss of composite resin CAD/CAM blocks after toothbrushing. Five composite resin blocks (Block HC, Cerasmart, Gradia Block, KZR-CAD Hybrid Resin Block, and Lava Ultimate), one hybrid ceramic (Vita Enamic), one feldspar ceramic (Vitablocs Mark II), one PMMA block (Telio CAD), and one conventional composite resin (Filtek Z350 XT) were evaluated. Surface roughness (Ra) and gloss were determined for each group of materials (n=6) after silicon carbide paper (P4000) grinding, 10k, 20k, and 40k toothbrushing cycles. One-way repeated measures ANOVA indicated significant differences in the Ra and gloss of each material except for the Ra of GRA. After 40k toothbrushing cycles, the Ra of BLO and TEL showed significant increases, while CER, KZR, ULT, and Z350 showed significant decreases. GRA, ENA, and VIT maintained their Ra. All of the materials tested, except CER, demonstrated significant decreases in gloss after 40k toothbrushing cycles.

Keywords: Composite resin, Gloss, Surface roughness, Toothbrushing

INTRODUCTION

In dentistry, many different CAD/CAM blocks used in preparing restorations are available commercially, and their use has gained in popularity. Restorations prepared from CAD/CAM blocks offer uniform material quality, reproducibility, and low fabrication cost. There are numerous types of CAD/CAM blocks available including lithium disilicate glass ceramics, leucite-reinforced glass ceramics, feldspathic glass ceramics, aluminum-oxide and yttrium tetragonal zirconia polycrystals, composite resin, titanium, and titanium alloy. Currently, the demands for esthetics, shorter treatment time, and nonmetallic restorations from both dentists and patients are critical challenges for researchers trying to develop the best restorative material. The advantages of a composite resin block are that it is easy to polish and to mill, does not require sintering or crystallization firing, and is repairable in the mouth. Newly available CAD/CAM composite resin blocks are fabricated by high-pressure/high-temperature polymerization resulting in improved mechanical properties. The flexural properties of composite resin CAD/CAM blocks were reported to be comparable to those of ceramic blocks and were suggested to be suitable for single premolar crown restorations. However, a restoration in a patient’s mouth is subjected to wear from several factors, such as food and daily cleaning.

The surface of a restoration placed on a tooth should be smooth and shiny. However, these surfaces may deteriorate intraorally due to several factors. Toothbrushing is a primary factor affecting the surface roughness and gloss of tooth-color-like restorations. Toothbrushing is an example of three body wear. The bristles of the toothbrush act as an antagonist while the toothpaste slurry is used as the medium. Many investigations have shown the effects of toothbrushing on the surface roughness and gloss of composite resins, in terms of brushing time, brushing force, and abrasivity of the particles contained in the toothpaste. An increase in toothbrushing cycles was shown to deteriorate the smoothness and glossy appearance of conventional composite resins. However, there is scant information regarding the effect of toothbrushing on composite resin CAD/CAM blocks. A study evaluating two-body wear, gloss retention, and surface roughness of CAD/CAM blocks found that all ceramic based, one nanocomposite, and two PMMA CAD/CAM blocks behaved similarly or better in terms of two-body and toothbrushing wear than natural enamel. A study demonstrated that PMMA CAD/CAM blocks had a lower wear rate than conventionally polymerized acrylic resin when enamel was used as the antagonist. Recently, the two-body and three-body wear characteristics of composite resin CAD/CAM blocks were evaluated using water and poppy seeds in vitro and it was reported that all CAD/CAM block materials tested exhibited low wear compared to direct posterior composite resins.

The most commonly used parameters for the evaluation of surface characteristics are surface roughness, gloss, and scanning electron microscope (SEM) images. The arithmetic average of the surface roughness in a two dimensional measurement (Ra), determined using a profilometer, is commonly used to quantitatively describe surface roughness, however, it does not describe the appearance of the examined surface. Surface roughness exceeding a threshold Ra value of 0.2 µm was claimed to increase plaque accumulation and staining in vitro. The determination of Ra values in vivo is not possible.
because the profilometer cannot be used intraorally. However, gloss is a feature that can be easily recognized and perceived by dentists and patients. Gloss characterizes the specular reflection of the restoration surface. Regression analysis has been used to predict the relationship between Ra and gloss of the examined surface. However, a consensus of their relationship has not been established.

Therefore, the objective of the present study was to investigate the surface roughness and gloss of CAD/CAM blocks after toothbrushing. The null hypothesis was that there would be no significant differences in the surface roughness and gloss of each CAD/CAM block after toothbrushing.

MATERIALS AND METHODS

Specimen preparation
Five composite resin blocks, one hybrid ceramic block, one feldspar ceramic block, one PMMA block and one conventional composite resin were used in the present study. Their compositions and manufacturers are listed in Table 1.

The CAD/CAM block specimens (8x8x2 mm) were prepared using a lathe and a low-speed diamond saw (Isomet Buehler, Lake Bluff, IL, USA). The specimens were embedded in the center of 12x20x10 mm autopolymerized resin (Fastray, Bosworth Company, Skokie, IL, USA) blocks. For the Z350 specimens, a 12x20x10 mm acrylic resin block was prepared using the same autopolymerized resin in silicone molds. A cylindrical cavity, 8-mm-diameter and 3-mm-depth, was drilled in the center of the acrylic block. The cavity was filled with Z350 and covered with a Mylar strip, and pressed flush under a glass slide. The composite resin was light activated with a light curing unit (GC Prima II, GC, Tokyo, Japan; light intensity: 600 mW/cm²) in contact with the Mylar strip for 40 s.

The specimens were wet-ground for 1 min each using P2400 grit (averaged abrasive particle size 12.2 µm), and P4000 grit (averaged abrasive particle size 6.5 µm) silicon carbide (SiC) paper (Leco, St. Joseph, MI, USA) at 150 rpm on a polishing machine (NANO 2000, Pace Technologies, Tucson, AZ, USA). The specimens were thoroughly rinsed with tap water, ultrasonically cleaned for 5 min to remove any debris, and dried with compressed air for 20 s.

Toothbrush testing
After storing the specimens for 7 days in 37°C deionized water, the specimens were mounted in a toothbrushing machine (V-8 Cross Brushing Machine, SABRI Dental Enterprises, Villa Park, IL, USA) operating with 55 mm back and forth brushing strokes at a frequency of 2 Hz. The specimens were brushed with a vertical force of 2.5 N on the toothbrushes (GUM Classic #411, Sunstar Americas, Chicago, IL, USA) following ISO specification #14569-1. The specimens and toothbrushes were immersed in containers of toothpaste slurry, prepared using a homogenizer from 50 mL of deionized water and 25 g of toothpaste (Colgate cavity protection, Colgate-Palmolive, Chonburi, Thailand; RDA80, Dicalcium phosphate as an abrasive system). The toothpaste slurry was periodically changed every 10,000 cycles. After 10,000 (10k) brushing cycles in the toothpaste slurry, the specimens were prepared for surface roughness and gloss determination as described below. The same specimens were subjected to an additional 10,000 (20k total) and 20,000 (40k total) toothbrushing cycles. The surface roughness and gloss were again determined after the 20k and 40k toothbrushing cycles.

Surface roughness measurement
The Ra value of each specimen was determined using a profilometer (Talyscan 150, Taylor Hobson, Leicester, England) equipped with an inductive gauge stylus with a 2 µm tip radius. The tracing length was 2 mm, the tracing speed was 500 µm/s, and the cut-off length was 0.25. Five parallel measurements, each 400 µm apart, were performed perpendicular to the toothbrushing direction. The Ra value was calculated as the average of the 5 measurements of each specimen.

Gloss measurement
Gloss was determined by a gloss meter (IG-331, Horiba, Kyoto, Japan) calibrated on a black glass standard provided by the manufacturer. The 60 degree measurement mode was selected. Each specimen was centrally placed over the reading aperture. The light beam was transmitted to the surface and reflected to the sensor. The measured area was oval-shaped (3x6 mm²). The specimen was measured, rotated 180 degrees, re-measured, and the gloss values were averaged.

Scanning electron microscope (SEM) observation
Two representative specimens of each material, one after P4000 grit SiC grinding and the other after 40k toothbrushing cycles, were selected and sputter-coated with gold. An SEM (JSM-5410LV, JEOL, Tokyo, Japan) was used to observe and capture images of the surfaces at an acceleration voltage of 20 kV and a magnification of 500×.

Statistical analysis
The Ra values and the gloss units of each material tested were separately analyzed using one-way repeated measures analysis of variance (ANOVA), followed by the Bonferroni method (α=0.05). The relationship between the Ra value and gloss units of each material was analyzed using linear regression.

RESULTS
The results of one-way repeated measures ANOVA of the Ra values of each material are shown in Table 2. All of the materials tested showed significant differences in Ra between the measuring stages (p<0.001) except the GRA group, where the differences were not significant.
Table 1  Materials tested and their compositions

| Material                      | Brand Code | Code | Manufacturer               | Shade/Size | Batch  | Composition                                | Monomer | Filler Composition                        | Mass% (Vol%) |
|-------------------------------|------------|------|-----------------------------|------------|--------|--------------------------------------------|---------|-------------------------------------------|--------------|
| Composite resin block         | Block HC   | BLO  | Shofu, Kyoto, Japan         | A3-HT/M    | 021401 | UDMA, TEGDMA                               |         | Silica powder, micro fumed silica, zirconium silicate | 61           |
|                               | Cerasmart  | CER  | GC, Tokyo, Japan            | A3-LT/14   | 1308261E | Bis-MEPP, UDMA, DMA                        |         | Silica (20 nm), barium glass (300 nm)     | 71           |
|                               | Gradia Block | GRA | GC                          | A3/14      | 1308012 | UDMA, Methacrylate copolymer               |         | Silica, Al-silicate glass, prepolymerized filler | 76           |
|                               | KZR-CAD    | KZR  | Yamamoto Precious Metal, Osaka, Japan | A3        | 01021410 | UDMA, TEGDMA                               |         | SiO₂ (20 nm), aggregated SiO₂-Al₂O₃-ZrO₂ (200–600 nm) cluster (1–6 µm) | 74           |
|                               | Lava™ Ultimate | ULT | 3M ESPE, St. Paul, MN, USA | A3-HT/14L  | N494437 | Bis-GMA, UDMA, Bis-EMA, TEGDMA              |         | SiO₂ (20 nm), ZrO₂ (4–11 nm), aggregated ZrO₂/SiO₂ cluster (0.6–10 µm) | 80           |
| Hybrid ceramic block          | Vita Enamic® | ENA | Vita Zahnfabrik H. Rauter, Bad Säckingen, Germany | 3M2-HT/EM-14 | 47630 | UDMA, TEGDMA                               |         | Feldspar ceramic enriched with aluminum oxide | 86 (75)      |
| Feldspar ceramic block        | Vitablocs® Mark II | VIT | Vita Zahnfabrik H. Rauter | A3C/I14 | 07BY0803 | —                                          |         | Feldspathic crystalline particles in glassy matrix | —            |
| PMMA block                    | Telio CAD  | TEL  | Ivoclar Vivadent AG, Schaan, Liechtenstein | A3        | T09738 | MMA                                        |         | —                                         | —            |
| Conventional composite resin  | Filtek™ Z350 XT | Z350 | 3M ESPE                     | A3        | N583256 | Bis-GMA, UDMA, Bis-EMA, TEGDMA, PEGDMA     |         | SiO₂ (20 nm), ZrO₂ (4–11 nm), aggregated ZrO₂/SiO₂ cluster (0.6–10 µm) | 73 (56)  

(Bis-GMA: Bisphenol A diglycidylether methacrylate; UDMA: Urethane dimethacrylate; Bis-EMA: Bisphenol A polyethyleneglycol diether dimethacrylate; TEGDMA: Triethylene glycol dimethacrylate; PEGDMA: Poly(ethylene glycol)-dimethacrylate; Bis-MEPP: 2,2-Bis(4-methacyloxy(polyethoxy)phenyl)propane; DMA: Dimethacrylate; MMA: Methyl methacrylate.

\(p=0.399\). The results of the post hoc comparison of the Ra values of each material are shown in Table 3. The BLO and TEL groups maintained their Ra values until 20k toothbrushing cycles, and demonstrated a significant increase in Ra after 40k toothbrushing cycles. In contrast, the CER, KZR, ULT, and Z350 groups presented a significant decrease in Ra after toothbrushing. The Ra values of the GRA, ENA, and VIT groups did not change significantly after 40k toothbrushing cycles.

The results of one-way repeated measures ANOVA of the gloss units of the materials are shown in Table 2. All of the materials tested showed significant differences in gloss between the measuring stages \(p<0.001\). The
Table 2  One-way repeated measures ANOVA of Ra value and gloss unit of each material tested between measuring stages

| Material | Ra       | p      | Gloss unit | p      |
|----------|----------|--------|------------|--------|
| BLO      | <0.001   | <0.001 |            | <0.001 |
| CER      | <0.001   | <0.001 |            | <0.001 |
| GRA      | 0.399    |        | <0.001     | <0.001 |
| KZR      | <0.001   | <0.001 | <0.001     | <0.001 |
| ULT      | <0.001   | <0.001 | <0.001     | <0.001 |
| ENA      | 0.018    |        | <0.001     | <0.001 |
| VIT      | <0.001   | <0.001 | <0.001     | <0.001 |
| TEL      | <0.001   | <0.001 |            | <0.001 |
| Z350     | <0.001   |        |            | <0.001 |

Table 3  Mean and Standard deviation of Ra values in µm of each material tested at each measuring stage

| Material | Measuring stage | SiC grinding | 10k | 20k | 40k |
|----------|----------------|--------------|-----|-----|-----|
| BLO      |                | 0.065 (0.007) | 0.075 (0.007) | 0.079 (0.005) | 0.102 (0.005) |
| CER      |                | 0.056 (0.002) | 0.042 (0.003) | 0.037 (0.008) | 0.044 (0.006) |
| GRA      |                | 0.051 (0.004) | 0.052 (0.003) | 0.048 (0.006) | 0.053 (0.007) |
| KZR      |                | 0.053 (0.002) | 0.064 (0.005) | 0.034 (0.003) | 0.037 (0.003) |
| ULT      |                | 0.060 (0.003) | 0.053 (0.007) | 0.055 (0.007) | 0.033 (0.003) |
| ENA      |                | 0.060 (0.008) | 0.043 (0.014) | 0.038 (0.004) | 0.050 (0.013) |
| VIT      |                | 0.046 (0.002) | 0.023 (0.003) | 0.029 (0.006) | 0.040 (0.006) |
| TEL      |                | 0.056 (0.004) | 0.082 (0.027) | 0.552 (0.505) | 3.299 (1.667) |
| Z350     |                | 0.060 (0.002) | 0.038 (0.006) | 0.047 (0.004) | 0.047 (0.005) |

Values with the same superscript letters in each row were not significantly different at p<0.05. mean (S.D.), n=6

Table 4  Mean and Standard deviation of gloss units of each material tested at each measuring stage

| Material | Measuring stage | SiC grinding | 10k | 20k | 40k |
|----------|----------------|--------------|-----|-----|-----|
| BLO      |                | 56.3 (3.0)  | 46.8 (3.5) | 42.0 (3.0) | 38.3 (2.8) |
| CER      |                | 73.8 (2.0)  | 80.5 (2.4) | 79.8 (1.0) | 83.4 (2.1) |
| GRA      |                | 56.7 (6.2)  | 45.3 (3.3) | 44.5 (3.7) | 43.8 (3.0) |
| KZR      |                | 71.7 (5.5)  | 56.0 (6.5) | 53.0 (5.3) | 45.8 (6.7) |
| ULT      |                | 83.7 (7.9)  | 76.1 (5.3) | 72.3 (4.8) | 72.4 (4.1) |
| ENA      |                | 59.7 (9.8)  | 42.5 (6.2) | 39.2 (5.7) | 37.3 (4.9) |
| VIT      |                | 89.0 (2.0)  | 71.9 (5.1) | 71.3 (4.4) | 72.6 (3.5) |
| TEL      |                | 75.8 (2.2)  | 56.6 (16.5) | 29.8 (21.5) | 8.3 (5.7)  |
| Z350     |                | 86.8 (3.2)  | 75.8 (3.5) | 74.0 (3.3) | 69.0 (3.4) |

Values with the same superscript letters in each row were not significantly different at p<0.05. mean (S.D.), n=6
results of the post hoc comparison of the gloss units of each material are shown in Table 4. Apart from the CER group, all of the materials tested presented a significant decrease in gloss after 40k toothbrushing cycles. In contrast, the CER group demonstrated a significant increase in gloss after the toothbrushing cycles.

The SEM images of each material tested after P4000 grit SiC grinding and 40k toothbrushing cycles are shown in Fig. 1. The BLO samples (Fig. 1-A1) demonstrated large and small spherical filler particles that have been reported to be silica and zirconium silicate, respectively. After 40k toothbrushing cycles, wide scratches were observed on the large silica particles and a large amount of small pits resulting from filler particle exfoliation were seen (Fig. 1-A2). The CER sample showed surface with minor scratches from SiC grinding (Fig. 1-B1). After toothbrushing, small filler particles homogenously dispersed on the CER surface were observed and the minor scratches seen in SiC ground showed an obviously decrease (Fig. 1-B2). The GRA samples (Figs. 1-C1, 2) demonstrated large irregularly shaped glass filler particles surrounded with smaller irregularly shaped particles. The surface characteristics between the SiC ground and 40k
Table 5 Linear regression of the relationships between Ra and gloss of each material tested

| Material | Slope  | Constant | R²       |
|----------|--------|----------|----------|
| BLO      | -423.24| 79.85    | 0.711*   |
| CER      | -279.08| 91.91    | 0.357*   |
| GRA      | -148.34| 55.14    | 0.014    |
| KZR      | 283.50 | 43.33    | 0.068    |
| ULT      | 154.77 | 68.44    | 0.109    |
| ENA      | 263.47 | 32.08    | 0.096    |
| VIT      | 419.59 | 61.78    | 0.262*   |
| TEL      | -13.35 | 55.94    | 0.530*   |
| Z350     | 435.00 | 55.59    | 0.286*   |

Predictor (R)
Coefficients of determination (R²)
* indicates significant correlation between Ra and gloss (p<0.01).

difficulties in standardizing the surface of the specimens under laboratory conditions due to the diversity of each material. A previous study stated that polishing using SiC paper with abrasive particles less than 9 µm, rendered a clinically acceptable surface roughness and gloss. Thus, P4000 grit SiC paper was selected in our study to obtain a standard baseline reference point.

In the present study, the design of the toothbrushing wear protocol followed the ISO technical specification on brushing force (2.5 N) as employed in previous studies. Soft bristle type toothbrushes and toothpaste were used as in a previous study. Toothpastes containing less abrasive particles may slow the rate of gloss reduction with less increase in the surface roughness of composite resin. A high number of toothbrushing cycles are necessary to produce an unequivocal effect on the roughness and gloss of the materials’ surfaces.

To evaluate material surface characteristics, several parameters have been used to investigate the surface of a material. Some investigators measured the volume loss from surface wear. In the present study, three parameters were chosen for evaluating the alteration of surface morphology after polishing and toothbrushing. Surface roughness (Ra) is an important laboratory parameter based on the depth of the scratches present on a material’s surface. Surface gloss is a parameter that is more clinically perceptible to clinicians and patients. SEM provides an overall understanding of a material’s surface morphology. Therefore, it is desirable to evaluate surface characteristics both quantitatively and qualitatively.

The statistical analyses indicated that significant differences were found in Ra between the measuring stages for each material tested except the GRA group, which maintained its Ra value. GRA consists of large irregularly shaped silicate glass and numerous prepolymerized filler particles that could possibly protect
its soft resin matrix from toothbrushing as observed in the SEM images. It is also interesting that the Ra values of the ENA and VIT samples were not significantly different between SiC grinding and 40k toothbrushing cycles evaluations. This greater wear resistance might be attributed to the strong ceramic network structure and greater hardness values of these materials\(^{18}\). These findings are consistent with a recent study that reported the surface hardness of ENA and VIT was relatively high when compared to the other materials tested\(^{28}\). The BLO and TEL samples showed a significant increase in Ra after 40k toothbrushing cycles. BLO, which consists of large spherical shaped silica filler particles with less filler content, is easily abraded from toothbrushing as seen in our SEM analysis. TEL is a PMMA block with no filler content. Therefore, it is reasonable that toothbrushing can easily create scratches along the brushing direction resulting in extremely high increases in Ra after 40k toothbrushing cycles. This result is supported by that of a previous study that showed that PMMA CAD/CAM blocks exhibited higher vertical wear loss compared with ceramic blocks\(^{17}\). The CER, KZR, ULT, and Z350 samples showed significant decreases in Ra after the toothbrushing cycles. This was due to their composition that consists of small-sized filler particles. The high filler loading and small-sized filler particles results in less distance between the filler particles. This might contribute to the better toothbrush wear resistance observed in our study as supported by previous investigation on the effect of filler particle size in the monomodel experimental composite system\(^{29}\).

All of the materials tested demonstrated significant differences in gloss units between the measuring stages. ADA specifications state that the gloss units of a polished restoration should range from 40–60\(^{29}\). In the present study, the gloss units of all the materials were from 56.3–89 which were diverse due to the difference in the composition of each material. However, these values were within the acceptable range after SiC grinding. This demonstrated the effectiveness of the P4000 grit SiC abrasive paper in rendering a high gloss on the sample's surfaces regardless of nature of the materials. This result corresponded to that of a previous study stating that particle sizes of <9 µm can provide improved gloss of a material\(^{20}\). The gloss of all materials tested showed significant decreases after 40k toothbrushing cycles except for the CER samples, which showed a significant increase. The gloss units of the composite resin blocks and ceramic blocks were still within the ADA's range after 40k toothbrushing cycles except for the TEL samples, which are composed of PMMA. The gloss of the TEL samples was completely eradicated by toothbrushing, as was seen in a previous study\(^{16}\). The CER samples demonstrated increased gloss units after 40k toothbrushing. This result might be attributed to well-distributed spherical nanosized filler particles. The SEM images of the CER samples showed no aggregated filler particles, which supports that the nano-sized filler particles are well distributed. This composition is believed to be self-polishing during toothbrushing.

The results of the present study indicated that most of the composite resin CAD/CAM blocks were comparable or better to ceramic blocks in terms of Ra and gloss retention, especially the CER samples, which maintained their surface characteristics after toothbrushing. The Ra values of the composite resin and ceramic blocks at each measuring stage were less than 0.2 µm, which is the threshold limit of plaque accumulation proposed by Bollen et al.\(^{20}\), and also below 0.64 µm, which is the average roughness value of enamel\(^{10}\). This suggests that the surface roughness of all the CAD/CAD blocks evaluated after toothbrushing would not be susceptible to plaque accumulation and staining. Furthermore, differences in Ra can only be discriminated by patients when the difference is over 0.5 µm\(^{31}\). Restorations visually appear to be smooth when a surface has a roughness of less than 1 µm Ra\(^{32}\). However, the Ra of the TEL blocks exceeded these threshold limits. Therefore, TEL blocks are only suggested to be used for provisional restoration as suggested by the manufacturer and should not be used for more than 12 months.

The surface characteristics after toothbrushing of the ULT samples were similar to those of the Z350 samples. This result is in agreement with that of a previous study\(^{16}\). This result indicated that the new polymerization method used in this material did not improve its toothbrush wear resistance or gloss retention.

The present study only provided information on the surface roughness and gloss of CAD/CAM blocks after toothbrushing in vitro. Many parameters have to be carefully evaluated to better understand the surface characteristics of the composite resin CAD/CAM blocks. Furthermore, long-term clinical observations of restorations in the mouth are recommended.

**CONCLUSION**

Within the limitations of the present study, it can be concluded that most of the composite resin CAD/CAM blocks are comparable or better compared with ceramic blocks regarding Ra and gloss after toothbrushing, especially the CER blocks that maintained their surface characteristics. Therefore, it is suggested that all the composite resin CAD/CAM blocks evaluated in the present study possess an acceptable toothbrush wear resistance.

**ACKNOWLEDGMENTS**

We thank Dr. Kevin TOMPKINS for his critical review and editing of this manuscript.

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