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Evaluation of surface roughness of composites obtained by additive and subtractive manufacturing methods after sandblasting

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Abstract

Aim: The aim of this study was to observe the change in the surface roughness of composite samples produced by different production methods after sandblasting with aluminum oxide particles and to evaluate the effect of this on the composite material.

Methodology: The study tested three subtractive method composites (GC Cerasmart [GC], Vita Enamic [VE] and Grandio Voco [GV]) and one additive method composite (3D Formlabs [3D]) were used. Each subtractive composite had 11 samples (14 x 14 x 2 mm) prepared with an Isomet low-speed saw, whereas the additive composite had 11 specimens produced using an SLA-based 3D printer (Form 2; Formlabs Inc). For roughness measurements and sandblasting, the samples were marked with an adhesive circular paper. Surface roughness was measured using a MarSurf SF1 profilometer, with three readings per sample. Sandblasting with aluminum oxide particles (50 µm) was performed using an Aquacare twin in-mouth sandblaster, and surface roughness measurements were repeated. Statistical analysis was performed using one-way analysis of variance (ANOVA) via SPSS 26, with significance set at p=0.05.

Results: Among the composite samples, Vita Enamic (VE) had the highest average roughness value, and 3D Formlabs (3D) had the lowest. VE had a mean roughness value of 0.4575 µm, GC had a mean roughness value of 0.4627 µm, GV had a mean roughness value of 0.665 µm and D had a mean roughness value of 0.4575 µm. All groups were compared pairwise with each other. A significant difference was found between the GV-D, VE-D, GC-GV, GC-VE, and GC-D group pairings (p<0.05). There was no significant difference between the GV-VE and GC-D group pairings (p>0.05).

Conclusion: Sandblasting with aluminum oxide was observed to increase the roughness of the materials, and the roughness varied depending on the nature of the material. Further studies are required to investigate the effects of roughness on the bonding.

Keywords: CAD-CAM, composite, surface roughness, wear, sandblasting, 3D printing

Introduction

Composite resin materials, which are frequently used in dentistry, have been developed over the years; however, they cannot be applied in every case or in every cavity.

Composite restorations are divided into two as direct and indirect. Direct restorations are restorations made by applying the composite resin directly to the tooth in the mouth and hardening it. It is completed in a single session. It is less invasive (provides protection of tooth tissue). It is a more economical and faster solution. It is aesthetically successful but can be colored over time. It is ideal for the restoration of small and medium-sized caries. However, isolation problems in these restorations make it difficult to apply. In addition, direct composite resin restorations have disadvantages such as polymerization shrinkage and insufficient carbon double bond conversion. Therefore, indirect composites are also used in some cases (1, 2).

Indirect composite restorations are restorations that are prepared outside the mouth (in the laboratory or clinic) and then bonded to the tooth. They are completed in two or more sessions. They are more durable and resistant to abrasion. Better contouring and contact points are provided. Since it is prepared in the laboratory environment, aesthetics and color stability are higher. It is preferred for the restoration of larger defects. Apart from this, some indirect restorative materials can also be used, such as ceramics or hybrid materials (3, 4).

The advancement of CAD/CAM technology was driven by three challenges. The first challenge was ensuring the solution was sufficiently strong, particularly for posterior teeth. The fabrication of restorations that appeared authentic constituted the second challenge. The ultimate challenge entailed enhancing the ease, speed, and precision of dental repair. Owing to CAD/CAM technology, patients can receive restorations on the same day (5).

Currently, CAD-CAM devices are frequently used to fabricate these materials. Computer-aided design and computer-aided manufacturing are referred to as computer-aided design (CAD) / computer-aided manufacturing (CAM) (1). It is used as a quick prototyping technique in many engineering, scientific, and artistic fields to speed up the design process and ease the transition from concept to production. The use of CAD and CAM in dentistry has increased in the previous 20 years (6).

With multiple applications, this technology can be used in dental clinics and laboratories. It can be used in full-mouth reconstruction, orthodontics, fixed partial dentures, implant abutments, and indirect tooth restorations (inlays, onlays, veneers, and crowns) (7).

CAD-CAM technology can be divided into subtractive and additive manufacturing methods (5).

1. Subtractive manufacturing: In this method, a block of material is gradually carved to form the desired shape. Typically, metal or ceramic blocks are used for this purpose. The digital tooth model is sent to a CNC milling machine via a CAD-CAM system. The machine subtracts necessary components from the block to create the final tooth. This approach offers greater precision and speed than traditional manual methods.

2. Additive manufacturing: Teeth are created layer by layer using 3D printers. A digital model is made first, and the tooth is then produced using ceramic or resin in the printer. Layers are added one by one to form the tooth model. This method reduces waste and is useful for complex tooth shapes.

The inner surface of ceramic restorations can be treated with surface techniques, such as sandblasting, silica coating, acid, and laser roughening, to improve micromechanical retention, increase the surface area and wettability of restorative materials, and strengthen the bond between them and the resin cement (8).

Sandblasting is frequently used in glass-ceramics, polycrystalline ceramics, and composites (9). The recommended sandblasting pressure for composites, which is lower than that of ceramics and metals, is in the range of 0.1–0.2 MPa. The reason for the low recommended pressure is that the composites have lower Vickers hardness values than the glass ceramics. The Al_2O_3 particles used in the blasting process both clean the contaminated layer on the material surface and increase the surface area and wettability. Profilometers are widely utilized to gather quantitative data regarding surface topography. Ra is frequently chosen in research because it quickly and readily analyzes indentations and protrusions in general, despite its perception as a weak parameter, because it does not provide precise information on minor surface changes (10).

Our study aimed to observe the change in the surface roughness of composite samples produced with different production techniques by sandblasting with aluminum oxide particles and to evaluate the effect of surface roughness on the composite material.

The null hypothesis was that there would be no difference between the groups after the sandblasting procedure.

Materials and Methods

This study aimed to evaluate the changes in the surface roughness of samples manufactured by additive and subtractive methods after sandblasting. In this study, three different composite materials manufactured by a subtractive method (GC Cerasmart [GC], Vita Enamic [VE], Grandio Voco [GV]) and one material manufactured by the additive method (3D Formlabs [3D]) were used. The contents of these materials are shown in Table 1.

Eleven samples (14 x 14 x 2 mm) for each category of subtractively produced material were made with a low-speed precision saw (IsoMet Low-Speed Saw, Buehler, Lake Bluff, IL, USA). These samples were polished using #600 to #1200 silicon carbide (SiC) papers (3M ESPE, St Paul, MN, USA) while being cooled with water.

The samples for the 3D group were produced using the SLA 3D printer Form 2 (FormLabs, Somerville, MA, USA). Subsequently, they were light-cured using the Otoflash G171 device with an illumination exposure of 4000 lux under an atmosphere containing nitrogen oxide gas. Using isopropyl alcohol (98%), all the samples were cleaned for two and a half minutes using an ultrasonic cleaner (Sonorex RK 102 Transistor, Bandelin, Berlin, Germany). A single operator polished the samples, according to the manufacturer's instructions.

The surface roughness of all samples was assessed using a contact profilometer (Mahr GmbH, Marsurf PS1, Göttingen, Germany). The measurement area was designated on each sample for subsequent use after sandblasting. Sandblasting was performed using an Aquacare Twin Air Abrasion Unit (Aquacare, Velopex, Medivance Instruments Ltd. London, UK), and 53 µm of aluminum oxide was delivered. The device has a standard tip set to a hand-piece nozzle with a 0.6 mm (silver- coated) diameter that operates for 10 seconds at 1 cm below the surface under a constant water shroud and 5 bar (500 MPa) of air pressure. The surface roughness of the samples was evaluated following the sandblasting process to identify any changes

Table 1. Contents of the materials used.

Material	Symbol	Classification	Contents	Manufacturer
Vita Enamic	VE	Polymer-Infiltrated Ceramic	86% Feldspathic, 14% Polymer	Vita Zahnfabrik, Bad Säckingen, Germany
GC Cerasmart	GC	Resin Nano Ceramic	71% Silica and Barium Nanoparticles, 29% Composite Resin	GC Corporation, Tokyo, Japan
Grandio Voco	GV	Resin Nano Ceramic	Content information was not found	Voco GmbH, Cuxhaven, Germany
Formlabs Permanent Crown Resin	3D	Biocompatible Photopolymer Resin	Content information was not found	Formlabs Inc., Somerville, MA, USA

Statistical analysis

Data were analyzed using statistical packages of IBM SPSS V25 (SPSS version 26, IBM, Armonk, NY, US).

The normality of the distribution was verified, and the test was chosen based on a previous comparison analysis. One-way ANOVA analysis of variance was performed using the SPSS program. The alpha value was set to be $p=0.05$. Statistical significance was set at $p<0.05$.

Results

The composite sample with the highest average surface roughness value was found to be VE. The group with the lowest average surface roughness value was found to be 3D.

The average surface roughness value of VE was 0.4575 µm, whereas GC had an average surface roughness value of 0.4627 µm, GV had an average surface roughness value of 0.665 µm, and the 3D group had an average surface roughness value of 0.4575 µm. These values are presented in Table 2.

All groups were compared with each other in pairs. Significant differences were found between the GV-3D, VE-3D, GC-GV, and GC-VE pairs ($p<0.05$). However, no significant differences were found between the GV-VE and GC-3D groups ($p>0.05$).

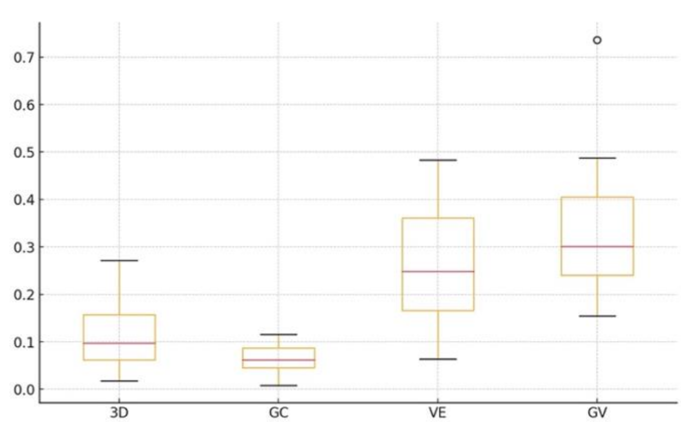

Figure 1. Box plot of the differences in roughness values after roughening

The differences in roughness values are shown in Figure 1. The mean and median of Δ roughness values and the lowest and highest roughness values in each group are shown in Table 3.

Table 2. Average roughness values of the composite groups

Composite Groups	Average Roughness Values
Vita Enamic	1.017 µm
GC Cerasmart	0.4627 µm
Grandio Voco	0,665 µm
3D Formlabs	0.4575 µm

Table 3. Mean and median of Δ roughness values and the lowest and highest roughness values in each group

	Mean	Median	Lowest	Highest
3D	0.116545	0.097000	0.018000	0.272000
GC	0.065273	0.062000	0.008000	0.116000
VE	0.267909	0.248000	0.064000	0.483000
GV	0.345364	0.301000	0.155000	0.736000

Discussion

After examining the results of this study, the null hypothesis that there would be no difference between the groups after the sandblasting procedure was rejected.

Mechanically roughening the surface is believed to i mprove bonding effectiveness in indirect restorations ba sed on composite materials more so than chemical tecni ques (11).

On the other hand, excessive roughness and cracks that develop during the roughening process could have adverse effects on the rest of the procedures (12).

Sandblasting is frequently used to strengthen the bonding and boost the surface energy of restoratives. Elsaka et al. reported that surface roughness might improve the adhesion of luting agent/CAD/CAM restorative materials by increasing the surface area. It is predicted that sandblasting will strengthen the bonds by enhancing the surface area, wettability, and mechanical interlocking. Consistent with these results, we discovered that, following sandblasting, the surface roughness values of every CAD/CAM restoration significantly increased. However, significant differences were observed among the groups tested in this study (9). Because various organic matrices and filler compositions may have responded differently during surface conditioning, the differences in the results might be attributable to the structure of the materials examined (13).

Saker et al. in a study conducted in 2013, they reported that they preferred 50 µm Al_2O_3 powder because it is often used to clean the inner surface of restorations (14). In addition, different studies have shown that very high particle size and blasting pressure do not increase bond strength and cause incompatible restorations owing to wear (15).

In this study, three composite materials produced by the CAD-CAM engraving method and one composite material produced by a 3D printer were roughened with 50 µm Al_2O_3 at a pressure of 5 bar and a distance of 1 cm. Vita Enamic had the highest roughness value. 3d Formlabs had the lowest roughness value.

Similar to our study, the roughness value of the Vita Enamic composite material after roughening with 50 µm Al_2O_3 for 15 s under a pressure of 2 bar was significantly higher than that of Cerasmart in the study by Dikici et al. (16).

However, Tekçe et al. found no significant difference in roughness between Vita Enamic and Cerasmart after roughening with 50 µm Al_2O_3 at 2.5 bar and 1 cm distance for 15 seconds (13).

In another study by Elsaka et al. the roughness of Vita Enamic was higher than that of Grandio Voco after roughening with 50 µm Al_2O_3 at 2.5 bar at a distance of 1 cm and 15 seconds (17).

In a study by Porto et al. Two polymer-based CAD-CAM (Lava Ultimate; 3M Oral Care and Vita Enamic; Vita Zahnfabrik) and 1 ceramic (Vitablocs Mark II; Vita Zahnfabrik) materials were roughened with aluminum oxide and 9 % HF acid and their surface roughness was measured. In this study, in parallel with our study, vita enamic had the highest roughness value when roughened with Al oxide (18).

In a study by Önöral et al. 5 different resin matrix ceramics; polymer infiltrated ceramic network (Vita Enamic), 2 resin nanoceramics (Lava Ultimate, Grandio Blocks), flexible nanoparticle filled resin (GC Cerasmart) and reinforced composite resin (Brilliant Crios) were sprayed with 50 µm aluminum oxide (Al_2O_3) particles at a distance of 10 mm from the hollow surface of each plate at 0.2 MPa air pressure for 20 seconds. Unlike our study, GC Cerasmart was rougher than Vita Enamic block. This difference may be due to the difference in the sandblasting device (19).

In the study by Muhammed et al. two resin matrix ceramic blocks (Lava Ultimate and Cerasmart) were roughened by 50-µm Al_2O_3 sandblasting, and the surface roughness and bond strength of the Cerasmart material increased in parallel with our study (20).

Limitations

The lack of in vivo oral environment circumstances is one of the study's limitations. All aging processes, such as those caused by salivary enzymes, water, acids, thermal attacks, and mechanical loading, occur simultaneously in clinical settings.

Another limitation of the present study is that only one type of surface treatment was tested, and different findings may be obtained with different surface treatments.

Conclusion

Roughening with aluminum oxide had a noticeable effect on the composites in terms of roughness. Further studies are required to examine the effect of roughness on bonding.

Disclosures

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