Experimental Article Comparative effect of Different Surface Treatments on the Shear Bond Strength between 3D-printed Artificial Acrylic Teeth and 3D-printed Denture Based Resins

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Abstract

Debonding of the artificial acrylic tooth from a denture base resin of a complete denture is a critical situation requiring substantial repair. Thus, improving the bond strength between artificial acrylic teeth and denture base resins (DBRs) is essential to prevent this clinical issue. Therefore, the aim of this study was to investigate the effect of surface treatments on the shear bond strength between artificial acrylic teeth and denture base resin fabricated from the 3D-printing method.

A total of 50 cylindrical 3D-printed artificial acryl teeth were divided into 5 groups (n=10), in which the surface of the teeth was treated as follows; 1) no surface treatment (control), 2) air abrasion, 3) methylmethacrylate (MMA), 4) MMA and post-cured with heat polymerization, and 5) a combination of air abrasion and MMA. All specimens were tested for the shear bond strength using a universal testing machine. The mode of failure was observed under a stereomicroscope. One-way analysis of variance (ANOVA) and Tukey's multiple comparisons was used for analyzing data.

The mean shear bond strength of all experimental groups was statistically significant different ($p<0.0001$), except for the groups treated with either air abrasion or MMA ($p>0.999$). Specimens treated with MMA and post-cured with heat polymerization exhibited the greatest shear bond strength. Surface-treated specimens showed a high percentage of mixed failure where cohesive and adhesive failures coincided.

The greatest shear bond strength was observed in denture base resins bonded to the artificial acrylic teeth treated with MMA and post-cured with heat polymerization. This could be considered as an alternative method to enhance the bond strength in a 3D-printed complete denture.

Experimental article (J Int Dent Med Res 2022; 15(4): 1416-1421)

Keywords: 3D-printed denture base resins, 3D-printed artificial acrylic tooth, methylmethacrylate, shear bond strength, surface treatment.

Received date: 30 July 2022 **Accept date:** 23 August 2022

Introduction

Complete tooth loss affects the quality of the edentulous patient's life, compromising the esthetics, phonetics, and functions in the orofacial region.[1] Therefore, one of the treatments for edentulism is a complete denture, in which the acrylic-based removable prosthesis serves as the substitute for the entire dentition and associated anatomical structures The denture is generally fabricated via conventional processing of heat-curing or self-curing polymerizations. Alternatively, the denture is fabricated through computer-aided design and computer-aided manufacturing (CAD/CAM) or additive technologies (3D-printing).[2] CAD/CAM or 3D-printed denture provides several advantages, including decreased patient appointments,[3] increased retention and mechanical strength, and a lower risk of denture-associated infection.[4]

The fabrication of CAD/CAM or 3D-printed dentures requires milling or printing the denture base resins (DBRs), followed by the assembly of the conventional, CAD/CAM, or 3D-printed denture teeth into the precut openings with a bonding agent.[5] Thus, a suitable bonding of the artificial teeth and DBR plays a critical role in enhancing the durability and strength of the denture.[6] Choi *et al.*, and Schneider *et al.*,

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reported that among the denture repairs, approximately 22- 30% of complete denture repairs involve tooth debonding, specifically in the anterior region of the denture.[6,7] Similarly, Darbar et al., estimated that the debonding failure could be up to 33% of all denture repairs.[8] Therefore, the strength of the bond between artificial teeth and denture base resins is an essential factor contributing to the longevity of removable prostheses.

To overcome these clinical concerns, several attempts have been proposed to enhance the bonding interface between acrylic teeth and conventional denture base resins, including methylmethacrylate monomer,[9] asperization,[10] laser-irradiation,[11] different technique for processing the denture base, as well as different types of artificial teeth.[12] However, little is known about the bond strength of artificial acrylic teeth and DBRs fabricated through the CAD/CAM or 3D-printed methods. Choi et al., reported that commercially available teeth bonded to heat-polymerized DBRs exhibited the highest shear bond strength. In contrast, teeth bonded to CAD/CAM or 3D-printed DBRs showed a significant decrease in their bond strength.[6] In addition, Prpic *et al*., demonstrated that denture teeth bonded to CAD/CAM or heat-polymerized DBRs exhibited similar shear bond strength values.[13]

It is obvious that the shear bond strength between 3D-printed artificial teeth and 3D-printed DBRs is equal to or lower than that of the conventional heat-polymerization.[6,13] However, in these studies, no bonding agent or other retention-generated surface treatments were included. Therefore, the aim of this study was to evaluate the effect of surface treatments on shear bond strength between artificial acrylic teeth and DBRs fabricated through the 3D-printing with direct light processing. The surface treatments involved in this study were either or a combination of resin used in making additive 3D-printed DBRs, methylmethacrylate, and air abrasion.

The null hypothesis was that the surface treatments would not affect the shear bond strength between 3D-printed artificial acrylic teeth and 3D-printed DBRs.

Materials and methods

Specimen preparation

The specimen used to test the shear bond strength was composed of 3D-printed acrylic artificial teeth and 3D-printed DBR. The acrylic artificial teeth were printed using 3D-printed acrylic resin (NextDent C&B MFH, 3D Systems, Rock Hill, SC, USA) and designed into cylinders with a diameter of 5 mm and 2.5 mm long. The denture base resins were printed using 3D-printed DBRs (NextDent Denture 3D, 3D Systems, Rock Hill, SC, USA) and shaped into squares (10x10x4 mm^3). All specimens (*n*=60) were printed using a 3D printer (NextDent 5100, 3D Systems, Rock Hill, SC, USA). The specimens were randomly assigned to various treatment groups (*n*=10) as follows;

Group 1; AD, 3D-printed artificial teeth, and 3D-printed DBRs were bonded through small volumes of 3D-printed DBRs. Then, the specimens were cured in an Ultraviolet curing device (LC-3DPrint Box, 3D Systems, Rock Hill, SC, USA) for 30 minutes. Group AD served as a control group.

Group 2; MAD, the surface of 3D-printed artificial teeth were mechanically treated with air abrasion with alumina particles (50 µm) at a pressure of 2.5 bars for 10 seconds. The air abraded-artificial teeth were bonded to 3D-printed DBRs with a similar protocol mentioned in the control group.

Group 3; CAD, the surface of 3D-printed artificial teeth was chemically treated with liquid conditioning; methylmethacrylate (MMA, Palabond, Heraeus Kulzer) 2 times with an interval of 30 seconds. Then, the liquid conditioned-artificial teeth were bonded with denture base resins using a similar protocol mentioned in the control group.

Group 4; CAD-H, the surface of 3D-printed artificial teeth was conditioned with liquid conditioning and bonded to denture bases as mentioned in Group 3. Then, the specimens were heat-cured at 100 °C for 30 minutes in a water bath (Memmert Waterbath WNE 29, Schwabach, Memmert, Germany).

Group 5; CMAD, the surface of 3D-printed artificial teeth was mechanically air abraded with alumina particles (50 µm) at a pressure of 2.5 bars for 10 seconds. Then, the air abraded surface was applied with liquid conditioning twice at 30 seconds intervals. The surface treated-artificial teeth were then bonded with denture base resins with a similar protocol mentioned in the control group.

After surface treatment and bonding were completed, all specimens were embedded in polyvinyl chloride (PVC) tubes with a diameter of 22 mm and a length of 15 mm. Next, the specimens were carefully submerged in type IV dental stone (Resin Rock; Whipmix Corp, Louisville, KY, USA), in which the surface of 3D-printed DBRs was parallel to the edge of a PVC tube. Finally, the specimens were allowed to dry at room temperature for 24 hours (Figure 1).

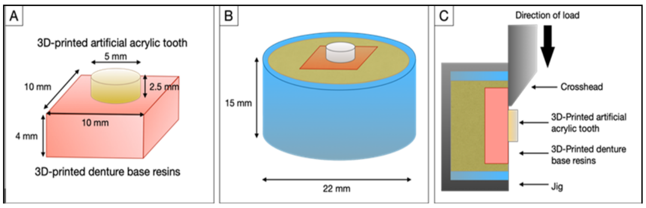

Figure 1. Schematic diagram of specimen and shear bond strength test. A) schematic diagram of 3D-printed acrylic denture tooth bonded to 3D-printed denture base resins, B) schematic diagram of embedded specimen, and C) schematic diagram of shear bond strength test.

Shear bond strength test

The shear bond strength was examined using a Universal Testing Machine (Shimadzu AGS-X, Kyoto, Japan). The shear bond strength test was performed with a special jig at a crosshead speed of 0.5 mm/min until bonding failure occurred.[14-16] Then, the shear bond strength was calculated by dividing the force at which bond fracture occurred by the area of bonding.

Failure analysis

The failure mode was clarified and characterized as follows; 1) adhesive failure of the 3D-printed artificial acrylic tooth and 3D-printed DBR interface, 2) cohesive failure of 3D-printed artificial acrylic tooth or 3-D printed DBR (failure occurs in the body of the 3D-printed artificial acrylic tooth or 3D-printed DBR), and 3) mixed failure were a combination of both. The fracture surfaces were investigated under a stereomicroscope (Leica Zoom 2000, Leica Microsystems GmbH, Wetzlar, Germany) at 40X magnification to identify the failure mode.[17-18]

Statistical analysis

The data were expressed as mean and standard deviations. The shear bond strength for each experimental group was compared using a one-way analysis of variance (one-way ANOVA) combined with the modification of Tukey's adjustment for pairwise multiple comparisons. A *p*-value of less than 0.05 was considered statistically significant.

Results

The mean shear bond strength of various experimental groups was displayed in Figure 2. There were statistically significant differences in mean shear bond strength amongst all experimental groups ($p<0.0001$), except for the mean shear bond strength between CAD and MAD groups ($p>0.999$). The shear bond strength of all surface-treated groups was statistically significant higher than that of the control group ($p<0.001$). CAD-H exhibited the highest shear bond strength (23.49±0.91), followed by MCAD (18.18±20.97), CAD (16.13±1.15), MAD (16.17±1.30), and AD (13.73±1.15) control groups.

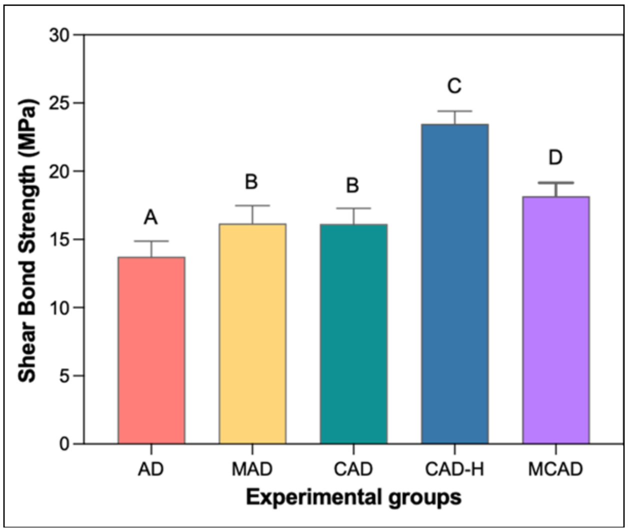

Figure 2. Shear bond strength of all experimental groups. Statistically significant differences were identified among non-surface treated and surface-treated groups ($p<0.0001$). Identical letters denote no statistically significant treatment group differences after adjustment for multiple comparisons.

According to the group, the descriptive analysis of the modes of failure is illustrated in Figure 3. Stereomicroscopy images of fractured surfaces are displayed in Figure 4. Mixed failure was the most frequent failure mode observed in all surface-treated groups. The MAD and CMAD groups exhibited only mixed failure, whereas; CAD and CAD-H showed a combination of mix failure, cohesive and adhesive failures. However, adhesive failure accounted for the highest percentage of failure modes in the control group.

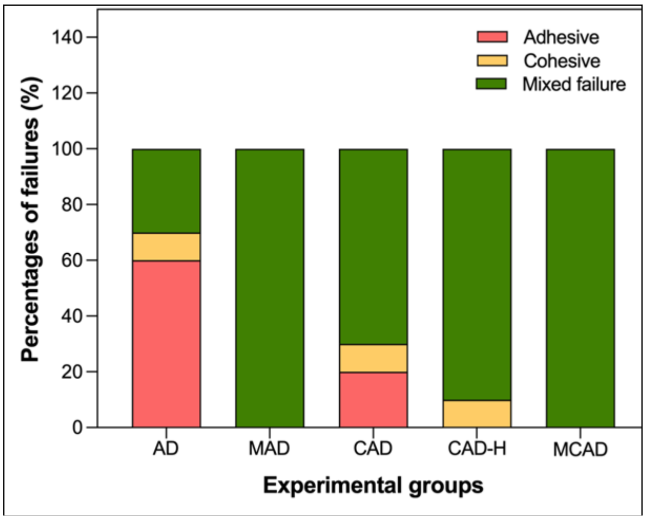

Figure 3. Percentage of mode of failures in all experimental groups.

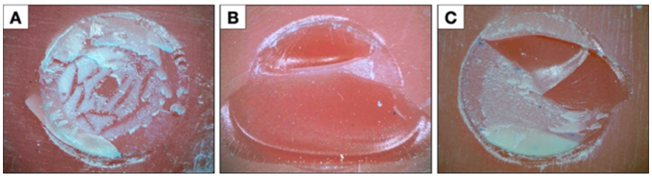

Figure 4. Mode of failure, A) adhesive failure, B) cohesive failure, and C) mixed failure.

Discussion

The null hypothesis was rejected as the results showed that the shear bond strength was significantly different amongst the experimental groups ($p<0.0001$). Our results showed that the surface treatments, both mechanical and chemical methods, enhanced the shear bond strength of 3D-printed artificial acrylic teeth and 3D-printed DBRs. The shear bond strength of MAD group was higher than that of the non-surface treated group. As expected, roughening the surface of artificial acrylic teeth increased the surface area available for bonding. The air abrasion also eliminated the saturated surface layer, exposing the subsurface layer. As a result, the subsurface layer exhibited higher free surface energy, which could contribute to an increase in bond strength.[19,20] These findings with air abrasion treatment were in accordance with the study of Bahrani *et al*. The authors demonstrated that air abrasion treatment of the ridge lap area of the denture teeth and denture base resins increased their shear bond strengths regardless of the type of polymerization.[19]

Another method to improve the bond strength of 3D-printed artificial acrylic teeth and 3D-DBRs was applying the adhesive agent. In this study, the specimens treated with methyl methacrylate-based monomer exhibited statistically significant higher shear bond strength than that of the control group. However, the bond strength was similar to the air-abraded group. It is well acknowledged that the methyl methacrylate monomer causes a swelling phenomenon, enhancing the diffusion of the monomer and creating a polymer bonding network that increases the bond strength between artificial acrylic teeth and denture base resins.[21] The findings are in agreement with Cleto *et al*., who evaluated the bond strength of artificial acrylic teeth and 3D-printed denture base resin using different bonding agents. The results showed that the shear bond strength between acrylic teeth and 3D-printed denture base resins was improved upon the application of methyl methacrylate monomer.[22]

The findings showed that the CAD-H group exhibited the highest shear bond strength, which was approximately 1.7 times higher than that of the control group. This could be the fact that the 3D-printed artificial acrylic teeth and 3D-printed DBRs were chemically treated with an adhesive agent under light-activated polymerization, then post-cured with thermal polymerization. The combined effect of photo and thermal polymerization may explicate the post-curing method's significant effect on the shear bond strength of the 3D-printed material. It is well acknowledged that light intensity and temperature have a noticeable impact on the degree of double bond conversion and polymer characteristics.[23] Thermal polymerization has been associated with a reduction in the resin monomer's viscosity and an increase in free radical movement. As a result, polymer chains with a higher degree of cross-linking are developed, leaving less residual monomer content than that of the light- or auto-cured polymerization.[23-25] This is in agreement with various studies.[6,26] Perea-Lowery *et al*. demonstrated the effect of post-curing methods on the mechanical properties of 3D-printed denture base materials. The results showed that increasing the temperature during a post-curing process enhanced the mechanical strength of the resin monomers used for 3D-printing dental appliances.[26]

We also investigated the combined effect of air abrasion and methyl methacrylate-based bonding agent on the shear bond strength between the 3D-printed artificial acrylic teeth and denture base resins. It showed that both air abrasion and bonding agent slightly enhanced bond strength, increasing 1.12 times, compared to the bond strength in either MAD or CAD groups. The findings could be indicated that there was a slightly synergistic effect when combining both mechanical and chemical methods. This is in agreement with Saavedra *et al*., that the shear bond strength between acrylic teeth and denture base acrylic resin treated with both air abrasion and methyl methacrylate-based bonding agent were no statistically significant different to other groups treated with either air abrasion or methyl methacrylate-based bonding alone. Therefore, there was no synergistic effect of mechanically air abrasion and chemically methyl methacrylate-based bonding agent on the shear bond strength of acrylic denture tooth and denture base resins.[27]

Non-surface treated control group exhibited mostly adhesive failure, whereas high percentages of cohesive and mixed failures were observed in the surface-treated groups. This is in accordance with the previous study. Taghva *et al*., reported that the specimens with lower shear bond strength were broken from adhesive failure. The cohesive and mixed failures were observed in the specimens with higher shear bond strength.[28] Adhesive failure is considered the least acceptable mode of failure due to the lack of strength between the acrylic denture teeth and denture base resins. In contrast, in cohesive failure, the bond strength is higher than the resistance of each material alone. Therefore, cohesive failure occurs on the material with lower strength than the other.[1]

One of the limitations of the present study was that the effect of post-curing with heat polymerization on the shear bond strength of 3D-printed artificial acrylic teeth and 3D-printed DBRs after treated with both mechanical and chemical methods should be investigated in future studies. In addition, all experiments should be assessed intraorally since it was unlikely to absolutely replicate the oral environment due to the *in vitro* nature of the experiment.

Conclusions

Within the limitations of this study, it was concluded that post-cured with heat polymerization of 3D-printed artificial tooth and 3D-printed DBRs after surface treated with methylmethacrylate monomer has the greatest shear bond strength compared to other surface-treated groups without post-cured with heat polymerization. Therefore, this could be considered an alternative method to improve the shear bond strength of the 3D-printed artificial tooth and complete denture base resins.

Acknowledgements

This study was supported by the Faculty of Dentistry Research Fund and Thammasat University Research Unit in Restorative and Esthetic Dentistry, Thammasat University, Thailand.

Declaration of Interest

The authors report no conflict of interest.

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