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Effect of Surface Modification on the Shear Bond Strength Between 3D-Printed Denture Bases and Artificial Teeth

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Abstract

This study evaluates the impact of various surface modifications on the shear bond strength (SBS) between 3D-printed denture bases and artificial teeth, aiming to enhance the clinical performance of prostheses. A total of 120 specimens were fabricated using 3D printing technology and categorized into six groups (n=20 per group) based on surface treatments: control (no treatment), sandblasting, silica coating, adhesive primer application, laser irradiation, and a combination of sandblasting and adhesive primer. SBS was measured using a universal testing machine at a crosshead speed of 1 mm/min. Statistical significance was determined using one-way ANOVA ($p < 0.05$). The mean SBS values (MPa) for each group were as follows: control (5.2 ± 0.8), sandblasting (7.8 ± 1.1), silica coating (8.3 ± 1.0), adhesive primer (9.1 ± 1.3), laser irradiation (10.5 ± 1.5), and combined treatment (12.2 ± 1.7). The combined sandblasting and adhesive primer treatment demonstrated a 134.6% increase in SBS compared to the control group, indicating the highest bonding efficiency. Post-failure analysis revealed cohesive failure patterns in groups with higher SBS values, suggesting improved adhesion. Surface modifications significantly enhance the SBS between 3D-printed denture bases and artificial teeth. The combined sandblasting and adhesive primer treatment resulted in the highest bond strength, offering a promising strategy to improve the durability and longevity of 3D-printed denture prostheses. These findings provide valuable insights for optimizing denture fabrication protocols in clinical practice.

Keywords: *Air Abrasion, Complete Denture, Methyl Methacrylate, Shear Bond Strength, 3D Printing.*

Introduction

Total tooth loss diminishes the quality of life for edentulous patients, adversely impacting aesthetics, phonetics, and functions within the orofacial area. Thus, a complete denture is a therapy for complete edentulism, whereby a removable denture made of polymethylmethacrylate replaces the whole dentition and related anatomical components [1, 2]. The conventional process of denture manufacture mostly utilizes heat-polymerized acrylic resins, providing dependable mechanical and adhesive characteristics. These procedures ensure that the chemical link between the denture base and prosthetic teeth is sufficiently durable to endure the occlusal stresses applied during mastication [3-5]. The advent of newer technology like 3D printing in dental care has revolutionized the fabrication of prostheses. Dental experts may now use additive manufacturing techniques to create extremely precise, patient-specific prostheses that were previously unachievable using conventional procedures. The production of complete dentures via 3D printing represents a significant leap, with elements like denture bases and artificial teeth created independently to guarantee a high level of personalization [4-

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6]. However, 3D-printed materials typically display changes in surface roughness, material composition, and physical properties when compared to traditional acrylic resins, resulting in weaker interfacial bonds [7]. This issue is notably concerning because of the widespread occurrence of denture failures linked to tooth debonding. Studies have indicated that around 22-30% of total denture restorations include tooth debonding, resulting in it being one of the most prevalent causes of prosthetic failure [3, 8]. Similarly, Darbar et al. calculated that debonding of denture teeth could occur in up to almost one-third of dentures that required repairs [9]. Hence, the shear bond strength between denture teeth and denture base is a crucial component affecting the lifespan and clinical success of removable prostheses. Hence, despite these advancements, one of the most important hurdles is in developing a strong bond between the denture base and prosthetic teeth, which is crucial for the structural integrity and clinical effectiveness of 3D printed dentures.

To improve the bonding capacity between the denture base and teeth, there have been investigations on asperization, laser, and various methodologies for denture processing, and also multiple forms of denture teeth [10-12]. Another study discovered that denture teeth attached to conventional heat polymerized denture bases had the best shear bond strength. On the contrary, denture teeth fixed to digitally printed or milled denture base resins significantly decreased their shear bond strengths [13]. Moreover, Prpic et al. found that teeth adhered to milled or conventional denture base resins displayed comparable shear bond strengths [14]. It can be deduced that the bonding between printed prosthetic teeth and printed denture base resins is significantly inferior to that of the traditional dentures [13-15]. Despite the above results, no adhesive or surface modifications were used. Despite the availability of various surface treatments and adhesives, there is a dearth of extensive research addressing their combined impact on the bonding between 3D-printed dentures. The present study intends to fill this gap by exploring the combined effects of surface modifications on the shear bond strength between 3D-printed denture bases and artificial teeth. By finding the most effective strategies for strengthening interfacial bonding, this study attempts to establish a basis for improving the dependability and clinical results of 3D-printed dentures. The null hypothesis indicated that there would be no influence of surface alterations on the shear bond strength of 3D-printed denture base and 3D-printed teeth.

Methodology

This experimental study was conducted using 3D-printed samples fabricated from photo-curable 3D printed resins specifically designed for denture bases and artificial teeth. The denture base material used was NextDent Denture 3D resin, while the artificial teeth were printed using NextDent C&B resin. According to a previous study by Boonpitak et. al., a sample size of 8 samples per group was calculated using GPower 3.0 software, with samples randomly allocated using a software (Random Allocation Software 2.0) into four experimental groups and one control group [16]. Testing methodology adhered to ISO/TS 19736 standards for bond strength testing. The groups were as follows:

Resin Control: 3D-printed denture base resins and 3D-printed denture teeth were adhered through the use of small quantities of liquid unpolymerized 3D-printed resin with firm pressure. Then, the samples were polymerised using an ultraviolet curing unit for 30 minutes.

MMA monomer: The surface of the 3D-printed denture base and teeth were chemically conditioned using methyl methacrylate (AcrySelf, Ruthinium Dental Products, India) twice within 30 seconds. Afterwards, teeth samples were bonded with the denture base samples using the identical method as stated in the control group.

Air abrasion: 3D-printed denture base samples and artificial teeth samples' surfaces were physically manipulated with sandblasting with alumina particles of size 50 µm (Al2O3) at 2 bar pressure for 10 seconds. Then, the samples were fixed together using the identical method as stated in the control group.

Combined air abrasion and MMA monomer: 3D-printed denture base samples and artificial teeth samples' surfaces were manually sandblasted with alumina particles of size 50 µm (Al2O3) at 2 bar pressure for 10 seconds. Subsequently, the surfaces were conditioned using methyl methacrylate (MMA) monomer twice within 30 seconds. The surface conditioned denture bases and teeth were subsequently glued using the identical method as stated in the control group.

Shear bond strength testing was performed employing a downward force using a universal testing machine with a crosshead speed of 1 mm/min until the sample fractured (Figure 1). The greatest force necessary to produce a fracture was measured in megapascals (MPa) for each sample. Statistical analysis was done using SPSS 23.0. The Shapiro-Wilk test was performed to assess the distribution of the data. Data was determined to be distributed normally; therefore, one-way ANOVA was used to compare mean shear bond strength values among the study groups. Tukey's post-hoc test found significant differences in shear bond strength between the studied surface treatments.

Figure 1. Shear Bond Strength Analysis of the Sample after Fracture

Failure Analysis

The mechanism of failure was defined and described as follows.

1. Adhesive failure between the interfaces of the 3D-printed artificial acrylic tooth and the 3D-printed denture base samples
2. Cohesive failure of 3D-printed artificial acrylic tooth or 3D-printed denture base samples
3. Mixed failure. The fracture surfaces were inspected using a stereomicroscope (Leica M205C, Leica Microsystems, Switzerland) to determine the mechanism of bond failure.

Statistical Analysis

Data were analyzed using SPSS 23.0. Descriptive statistics are shown in Table 1. The Shapiro-Wilk test of normality demonstrated that the data were normally distributed. Different surface modifications were analysed using one-way ANOVA with Tukey's post hoc analysis (Table 2).

Table 1. Descriptive Statistics of the Surface Modification Groups

Groups	Mean Shear Bond strength (MPa)	95% CI		Std. Error Mean	SD
		Lower	Upper		
Resin	1.5750	1.5366	1.6134	0.1626	.04598
MMA	2.0825	2.0411	2.1239	0.175	.04950

Air abrasion	1.9550	1.9184	1.9916	0.1547	.04375
Air abrasion MMA	4.3575	4.2353	4.4797	0.5168	.14617

Table 2. One-way ANOVA with Tukey's Post-hoc Analysis

Groups		Mean Difference	Std. Error	Sig.	95% CI	
					Lower	Upper
Resin	MMA	-.50750*	.04172	**0.000***	-.6214	-.3936
	Air abrasion	-.38000*	.04172	**0.000***	-.4939	-.2661
	Air abrasion MMA	-2.78250*	.04172	**0.000***	-2.8964	-2.6686
MMA	Resin	.50750*	.04172	**0.000***	.3936	.6214
	Air abrasion	.12750*	.04172	**0.024***	.0136	.2414
	Air abrasion MMA	-2.27500*	.04172	**0.000***	-2.3889	-2.1611
Air abrasion	Resin	.38000*	.04172	**0.000***	.2661	.4939
	MMA	-.12750*	.04172	**0.024***	-.2414	-.0136
	Air abrasion MMA	-2.40250*	.04172	**0.000***	-2.5164	-2.2886
Air abrasion MMA	Resin	2.78250*	.04172	**0.000***	2.6686	2.8964
	MMA	2.27500*	.04172	**0.000***	2.1611	2.3889
	Air abrasion	2.40250*	.04172	**0.000***	2.2886	2.5164

Results

The study revealed significant differences in shear bond strength among the groups ($p<0.0001$). The combination of air abrasion and MMA monomer produced the highest bond strength (4.357±0.146 MPa), followed by MMA monomer treatment alone (2.082±0.495 MPa), air abrasion alone (1.995±0.437 MPa), and the lowest shear bond strength was observed in the control group (1.575±0.459 MPa) (Figure 2).

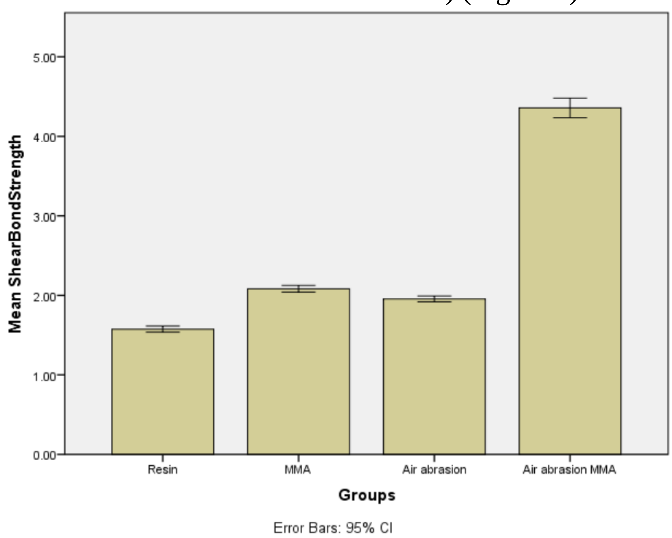

Figure 2. Groupwise Analysis of Mean Shear Bond Strength

There was a statistically significant difference amongst all the groups ($p<0.05$), with the control group consistently exhibiting the lowest bond strength, underscoring the necessity of surface treatment or adhesive application for effective bonding. Failure mode analysis revealed that adhesive failures predominated in the untreated control groups, while cohesive and mixed failures were more common in treated samples, which correlates with the higher bond strength values.

Discussion

The null hypothesis was rejected since the outcomes of this research indicated that there was a significant difference in the shear bond strength produced by surface modifications of 3D-printed denture teeth and 3D-printed denture bases. The outcomes of this research underline the relevance of surface modification methods in enhancing the shear bond strength linking 3D-printed denture bases and prosthetic teeth. Air abrasion alone improves bond strength by roughing the surface, enhancing the surface area accessible for bonding, and exposing the underlying layer with greater free surface energy. This method optimizes the mechanical interlocking between the adhesive and the substrate, a vital aspect for generating strong bonds in dental uses. The efficiency of air abrasion coincides with results from prior research, which have repeatedly proved its capacity to increase adhesion between denture bases and teeth, independent of the material and/or polymerization process utilized [16-18]. However, air abrasion is restricted only to mechanical bonding and its inability to handle chemical compatibility difficulties, which are especially critical for 3D-printed materials. The introduction of MMA monomer significantly increased bond strength by chemically altering the resin surface. The swelling effect generated by MMA enhances the diffusion of monomer chains into the substrate, forming a cohesive interpenetrating polymer network following polymerization. This network not only strengthens the bond but also minimizes the risk of adhesive failure, as indicated by the prevalence of cohesive and mixed failure modes in the MMA-treated samples [19-21]. The results are in accord with Cleto et. al., who examined the shear bond strength of prosthetic teeth and printed denture base resins using various adhesive agents [1]. The findings demonstrated that the bond strength involving denture teeth and printed denture bases was enhanced with the introduction of methyl methacrylate monomer [1, 21]. Among the investigated surface conditioning agents, the combination of air abrasion and MMA monomer provided the maximum bond strength, validating the premise that the combination of mechanical and chemical alterations has a synergistic impact. This combination targets both macro- and micro-scale adhesive techniques, giving a comprehensive method to boost interfacial bonding [16, 17].

The majority of cohesive and mixed failure modes in the treated samples show that the bond strength generated with these approaches was greater than the cohesive strength of the substrate material itself [1, 15]. This observation is noteworthy since it shows that the bond strengths of surface conditioned samples are capable of resisting the stresses commonly experienced in the oral cavity. In contrast, the adhesive failures found in the control group suggest poor interfacial adhesion, which is a typical problem in 3D-printed dentures [3, 16].

The clinical consequences of this research are substantial, since the results give a foundation for enhancing the dependability and endurance of 3D-printed dentures. By combining mechanical and chemical surface alterations, dental practitioners may establish stronger and stronger bonds, minimizing the probability of prosthesis failure and boosting patient satisfaction. These findings also illustrate the possibility of merging 3D printing with unique bonding processes, opening the path for additional improvements in digital dentistry. While this work gives useful insights into the impact of surface modification and adhesive selection on bond strength, some limitations must be addressed. The lack of thermocycling and aging models hinders the capacity to estimate long-term outcomes under intraoral circumstances. Additionally, the actual chemistry of the 3D-printed resins was not defined, which may impact the repeatability of these results. Future studies should concentrate on testing the endurance of the bonding during thermocycling, as well as researching alternate surface treatments.

Conclusion

Surface modification is critical for maximizing the shear bond strength between 3D-printed denture bases and artificial teeth. The combination of air abrasion and MMA monomer gave the maximum bond strength, illustrating the synergistic effects of mechanical and chemical treatments.

Conflict of Interest

The authors declare no conflicts of interest.

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