Journal of Chemical Health Risks

www.jchr.org

JCHR (2025) 15(6), 2128-2138 | ISSN:2251-6727

Effect of Surface Treatments on Shear Bond Strength of Novel 3d Printed Denture Teeth to Acrylic (Pmma) Denture Base Resins - An Invitro Study

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(Received: 27 October 2025 Revised: 05 November 2025 Accepted: 04 December 2025)

KEYWORDS

Edentulism

3D-printed denture teeth

PMMA denture base resin

Shear bond strength

Surface treatment

ABSTRACT:

Background:

Edentulism, or the complete loss of natural teeth, is a significant global health problem affecting quality of life and general well-being. Removable dental prostheses are traditionally fabricated using the lost wax technique with heat-polymerized polymethyl methacrylate (PMMA) resin bases and conventional denture teeth. With the advent of 3D printing, denture teeth can now be fabricated digitally; however, their bonding with PMMA bases remains a challenge. This study aimed to assess and compare the effects of mechanical (sandblasting) and chemical (methyl methacrylate, MMA) surface treatments on the shear bond strength of 3D-printed denture teeth to PMMA denture base resins.

Methodology:

An in-vitro experimental study was conducted on 30 samples, divided into three groups. The control group consisted of 3D-printed denture teeth bonded to PMMA resin without surface treatment. Group A (mechanical treatment) underwent sandblasting with 50 µm aluminium oxide particles at controlled pressure for 10 seconds to produce uniform roughness. Group B (chemical treatment) had methyl methacrylate applied to the bonding surface using a microbrush for uniform chemical modification, enhancing adhesive penetration. Shear bond strength was tested by applying compressive force until failure.

Results:

The mean compressive stress at maximum force was highest in Group A (26.38 ± 7.72 MPa), followed by Group B (20.85 ± 4.97 MPa), and the control group (15.05 ± 4.64 MPa). Statistical analysis showed significant differences between groups for both maximum force ($p = 0.002^*$) and compressive stress at maximum force ($p = 0.001^*$).

Conclusion:

Both mechanical and chemical surface treatments significantly enhanced the shear bond strength between 3D-printed denture teeth and PMMA denture base resin. Sandblasting produced the highest bond strength, suggesting it is more effective than MMA application. These findings highlight the importance of surface modifications in improving the durability and clinical performance of 3D-printed prosthetic restorations.

1. Introduction

Edentulism, or the complete loss of natural teeth, is a major global health issue that impacts the quality of life and general well-being of millions of people. According to Global burden of disease (GBD) in 2021, approximately 353 million people worldwide were edentulous, leading to a global age- standardised prevalence rate of 4.11 percent. Clinically, removable partial and complete dentures are commonly used to replace missing teeth and restore oral functioning. [1]

Removable Dental Prosthesis is traditionally made using the lost wax method, which involves using a heat polymerized polymethyl methacrylate (PMMA) resin foundation and traditional denture teeth. However, Removable dental prosthesis frequently receives complaints regarding debonding of denture teeth from the denture base, poor retention, mastication difficulties, and stability issues. Farideh Bahrani and Amir Ali, 2014 stated that one of the main issues in prosthodontics is the debonding of denture teeth from denture bases. According to earlier reports, debonded teeth account for 26-33% of denture repairs, which puts patients through stress and raises their expenses. [2,3] The bonding strength between different denture teeth and their denture bases can be strong enough to produce tooth breakage without debonding. If the bond between the parts resists until the materials fail, it fulfils its functional criteria.[4]Various factors, including ageing, ridge lap grinding, bonding agents, solvents or monomer-polymer solution application, surface grooving, tooth material, cross-linking agent concentration, denture base material, separating medium, impurities or wax contamination, thermocycling, microwave polymerisation, and polymerisation temperature rise, have been studied to impact the bond strength between artificial teeth and denture bases.[5]

Although removable dental prosthesis are the most often used dentures, modern and sophisticated fabrication methods have been adopted in clinical practice to minimise denture delivery time, streamline the manufacturing process, and lower overall production costs. Dentures can now be created using modern technology in addition to standard processing methods like heat curing and self-curing. [6]

There are two fabrication processes for digital removable dentures: Additive (3D printing), which stacks the acrylic material layer by layer, and Subtractive, which uses computer-aided design and computer-aided manufacturing (CAD/CAM) to mill the material with specific cutting tools guided by computer numerical control technology. Stereo lithography (SLA) and Digital light processing (DLP) are two methods for printing three-dimensional resin layers with high precision (20-150 µm). In both procedures, the acrylic denture foundation is milled or printed first, and the traditional CAD/CAM or 3D-printed denture teeth are affixed with a bonding agent. [7]

PMMA gained popularity for various dental applications due to its unique properties, including its low density, aesthetics, cost-effectiveness, ease of manipulation, and tailorable physical and mechanical properties. In addition to denture bases, other oral healthcare applications for PMMA include fabrication of artificial teeth, impression trays, temporary crowns, obturators for cleft palates, occlusal splints, printed or milled casts, dies for treatment planning, denture relining, and repair.[8] Advances in digital denture technology have revolutionized this field, allowing technicians to design aesthetic and functional occlusions digitally within restorative edentulous spaces. This shift from manual arrangement to CAD/CAM workflows has streamlined the fabrication process, enabling precision and customization in artificial teeth arrangement. [9]

Dentists can use 3D printing technology to produce models of their patients' teeth and jaws, which they can then use to plan and prepare for various dental operations. They can also develop physical replicas of the finished product to verify a correct fit and make any required alterations before it is manufactured. In addition to improving patient care, 3D printing can be more efficient and cost-effective than traditional manufacturing techniques since it allows for the on-demand fabrication of complicated and customised products, eliminating the need for huge volumes of inventory or specialised machinery. Although 3D printing has become a sensation in the world of technology and industry for a variety of applications, it is still in its early stages of development in dentistry. [10]

3D printing encompasses various techniques, including binder jetting, material extrusion, powder bed fusion, Stereolithography (SLA), Digital light processing (DLP), and selective laser sintering (SLS). Each method has distinct characteristics and applications, contributing to the diverse capabilities of 3D printing in prosthodontics and other fields. SLA is a widely used 3D-printing method in prosthodontics, particularly for creating custom dental prostheses such as crowns and bridges. This technology has progressively replaced conventional fabrication methods due to its capacity to produce complex structures with intricate geometries. [11]

Mohammed H. Alyami, 2024 stated that DLP is a rapid printing method. it is used for resin designs. Similar to SLA, DLP uses a light source to cure layers at once, which aids in speeding up the process. It is widely used in prosthodontics for dental restorations and orthodontic models. Owing to its rapid production, high precision, and personal customization, complete dentures, and implant teeth are easier to obtain. Additionally, the applications of 3D printing in dentistry can assist in providing patients with lower cost and more personalized services and simplify the complex workflow related to the production of dental appliances[12].

To enhance the shear bond strength between 3D-printed denture teeth and polymethyl methacrylate (PMMA) denture base resins, various surface treatment methods have been explored, including mechanical, chemical, and laser-based modifications. These treatments aim to improve micromechanical retention and chemical bonding between the two materials. Mechanical methods such as sandblasting with alumina particles and creating macro- retentive features (e.g., grooves or diatoric holes) have been shown to increase the surface area and promote mechanical interlocking, thereby enhancing Shear Bond Strength. [13]

A study conducted by Zahra A AlZaher et al 2020, demonstrated that sandblasting combined with the application of a silane coupling agent significantly improved the bond strength between denture teeth and base resins.[14] Chemical treatments involve applying solvents or adhesives to modify the surface chemistry, facilitating better bonding. The use of methyl methacrylate (MMA) monomer as a conditioning agent has been reported to enhance the bond strength between acrylic teeth and denture bases. [15]

Sandblasting and methyl methacrylate (MMA) application are widely used due to their effectiveness in improving adhesion. Sandblasting mechanically roughens the surface, increasing micromechanical retention and enhancing the interlocking between the two materials. This process creates a larger surface area for bonding and improves the penetration of the PMMA resin into the 3D-printed denture teeth. On the other hand, MMA application chemically modifies the surface by partially dissolving and softening the acrylic structure, promoting better chemical bonding between the two materials. Hata k et al stated that combined effect of mechanical and chemical surface treatments may result in superior Shear Bond Strength, reducing the risk of failure in clinical applications. [16]

While extensive research has been conducted on the bond strength of conventionally manufactured acrylic denture teeth to PMMA bases, limited data are available on the adhesion properties of novel 3D-printed denture teeth. Given the differences in material composition and surface characteristics of 3D-printed teeth, it is essential to evaluate the effectiveness of surface treatments specifically for these materials. This in vitro study aimed to assess and compare the effects of sandblasting and MMA application on the Shear Bond Strength of 3D-printed denture teeth bonded to PMMA denture base resins.

2. Objectives

The aim of the study is to evaluate the effect of surface treatments on shear bond strength of novel 3D printed denture teeth to acrylic (PMMA) denture base resins. The objectives of the study is to

1. To evaluate the shear bond strength of the samples without any surface treatment of 3D printed denture teeth to acrylic denture base resins.

2. To evaluate the shear bond strength of the mechanically treated (sandblasting with 50µm Aluminium oxide abrasive) 3D printed denture teeth to acrylic denture base resins.

3. To evaluate the shear bond strength of the chemically treated (Methyl methacrylate monomer resin) 3D printed denture teeth to acrylic denture base resins.

4. To compare the differences in the shear bond strength between the samples without any surface treatment, mechanically and chemically treated 3D printed denture teeth to acrylic denture base resins.

Methods

An experimental in-vitro study was conducted to assess and compare the effects of sandblasting and MMA application on the Shear Bond Strength of 3D-printed denture teeth bonded to PMMA denture base resins. in the Department of Prosthodontics, Thai Moogambigai Dental College and Hospital, Chennai, Dr.M.G.R Educational and Research Institute (Deemed to be University), Golden George Nagar, Chennai

The study was approved by Institutional Review Board and Institutional Ethical Committee with at Thai Moogambigai Dental College and Hospital, Dr.M.G.R Educational and Research Institute, (Deemed to be University) Golden George Nagar,Chennai-600 107. The IEC Reg No: 22312102002.

The sample size was estimated with the mean and standard deviation of the shear bond strength from the

Journal of Chemical Health Risks
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JCHR (2025) 15(6), 2128-2138 | ISSN:2251-6727

literature (1.52±0.24), assuming alpha=0.05, relative precision = 10 % of mean (1.52), then the sample size = 10 per group using the formula.

Total sample: 30

Total number of Groups: 3

Number of sample in each Group: 10

Control Group: 3D printed denture teeth to acrylic denture base resins without any surface treatment. (n0)

Group A: Mechanical treatment: The bonding side of the 3D -printed slice is treated using a sandblaster with the abrasive material Aluminium oxide abrasive particles size 50µm. Sandblasting is performed at a controlled pressure for about 10 seconds to ensure uniform roughness without damaging the material. (n1)

Group B: Chemical treatment Methyl methacrylate is applied using a micro brush to ensure precise and uniform coverage of the bonding surface. This chemical modification improves the penetration of adhesives or bonding agents into the treated surface, resulting in stronger adhesion. (n2).

A putty mould was made to create a wax block with a dimension of 1.5 x 1 cm to hold the sample. DPI® Heat cure denture base PMMA resin (Figure:1) was used to create a block with a 10mm diameter and 2mm thickness. Compressive molding technique was used for the curing of the rectangular blocks under uniform high pressure.

Then a standardised tooth model is designed using CAD software. 3D printing machine (UniFormation GK TWO) (Figure: 2) was used to print the 3D tooth model using JAMG HE® 3D Printer Photopolymer Resin (Figure: 3) Then the 3D printed tooth slice was bonded to acrylic denture base. The samples were segregated according to the groups.

Composition: Polymer consists of granules of Polymethyl methacrylate, benzoyl peroxide, Dibutyl phthalate, pigments, synthetic fibres, bismuth salt. And Monomer consists of methyl methacrylate monomer, hydroquinone and ethylene.

Composition: Monomers and Oligomers (Bisphenol A Glycidyl Methacrylate, Urethane Dimethacrylate, Triethylene Glycol Dimethacrylate, Ethoxylated Trimethylolpropane Triacrylate), Photo initiators (Camphor Quinone)

Control group: 10 samples were not exposed to any surface treatments and they were directly evaluated for the shear bond strength using INSTRON Universal Testing Machine E-3000. (n0)

Group A: 10 Samples were done with mechanical surface treatment sandblasting. The samples were exposed to the high-speed stream of aluminium oxide abrasive particles size 50µm for 30seconds from a distance of 10mm under 2 bar pressure to roughen the surfaces (Figure: 4), for better adhesion and to remove the contaminants.[33] (n1)

Group B: 10 Samples were done with chemical surface treatment Methyl methacrylate application. The samples surfaces were cleaned thoroughly with distilled water and dried it with compressed air to remove contaminants. A clean micro brush was used to apply a thin layer of MMA monomer (Figure: 5) directly on the prepared bonding surface of the resin block. The MMA monomer was left for 60 secs to dissolve and soften the acrylic surface. (n2)

Then the 3D printed tooth block was placed and bonded for all three groups. Thermocycling procedure consisting of 5000 cycles in a distilled-water bath at temperatures of 5–55 °C (Figure: 6). Each cycle lasted 60 s and involved the following steps: 20 s in a 5 °C bath, a 10-second transfer of the samples to another bath, 20 s in a 55 °C bath, and a 10-second transfer back to the 5 °C bath. The 3D printed tooth slice was prepared in a 5mm diameter and 2mm thickness (Figure 7, 8&9). The prepared tooth slice was placed in the Universal Testing machine,(INSTRON E-3000) (Figure: 10&11) the jig present in the UTM ensures the sample is held firmly in place during the application of compressive stress. The jig also allows for precise application of forces to test the materials mechanical properties. Then the shear bond strength, fracture resistance, flexural strength, tensile strength and elasticity were evaluated using for all three groups. The maximum force applied and the compressive stress for each group was recorded.

As the applied load increased, stress gradually accumulated at the interface between the 3D-printed tooth and the PMMA denture base resin (Figures 12, 13,

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JCHR (2025) 15(6), 2128-2138 | ISSN:2251-6727

and 14). Initially, the bonded interface resisted the load through mechanical interlocking and chemical adhesion. However, with continued loading, microcracks began to develop, particularly at points of stress concentration. These microcracks propagated along the weakest zones of the bond, ultimately leading to debonding once the interfacial strength was exceeded.

Statistical analysis : Statistical analysis was done using SPSS software version 26.0 [Armonak, NY: IBM Corp]. Descriptive statistics was done for the mean distribution of the maximum force and the compressive stress at Maximum force among three groups. Normality test was done using Kolmogorov Smirnov and Shapiro Wilk test. Data was normally distributed and hence the ANOVA test was used to find the difference between three groups. Tukey Post hoc test was done to find the inter group comparison. P value <0.05 was considered as statistically significant.

Compressive jig.

3. Results

In statistical results Shows that mean distribution of the maximum force given was high in Group A (235.58±52.98), followed by Group B (178.57±50.30) and control group (143±52.78). Mean distribution of the compressive stress at Maximum force was high in Group A (26.38±7.72) followed by Group B (20.85±4.97) and Control group (15.05±4.64). and there was a statistically significant differences between the groups for maximum force given (p value 0.002*) and compressive stress at maximum force (p value 0.001*). Table 2 Shows that for maximum force there was a statistically significant differences were seen between Group A and Control group (p value 0.001*) but there was no statistically significant differences seen between Group B and Group A (p value 0.53) as well as Group B and control (p value 0.30). For compressive stress there was a statistically significant differences were seen between Group A and Control group (p value 0.001*) but there was no statistically significant differences seen between Group B and Group A (p value 0.113) as well as Group B and control (p value 0.93).

Table 1: Analysis of variance test to find the differences between the groups

Parameters	**Control**	**Group A**	**GroupB**		
Maximum Force	143.8000±52.78929	235.5890±52.98149	178.5730± 50.30262	7.93	0.002*
Compressive stress	15.0580± 4.64538	26.3820± 7.72558	20.8560±4.97591	9.073	0.001*

Oneway anova p<0.05* significant NS; Not significant

Table 2: Post Hoc Tests

Parameters	Groups		Mean Difference	Sig.
Maximum Force [N]	Control	Group A	-91.78900*	.001
		Group B	-34.77300	.309
	Group A	Control	91.78900*	.001
		Group B	57.01600	.053
	Group B	Control	34.77300	.309
		Group A	-57.01600	.053
Compressive stress at Maximum Force	Control	Group A	-11.32400*	.001
		Group B	-5.79800	.093
	Group A	Control	11.32400*	.001
		Group B	5.52600	.113
	Group B	Control	5.79800	.093
		Group A	-5.52600	.113

4. Discussion

Removable Partial dentures and complete dentures hold significant importance in Prosthodontics. It restores masticatory and speech function, improves aesthetics and prevent tooth drifting and occlusal imbalance. They are cost effective, non-invasive and serve as both permanent and transitional solutions, especially beneficial for patients seeking affordable tooth replacement. [17]

Polymethyl methacrylate (PMMA) is the important unmodified acrylic materials used in dentistry. One of the most significant clinical advancements in recent years has been the integration of digital technology into prosthodontics practice. [18] Digital scanning, computer-aided design (CAD), and computer-aided manufacturing (CAM) have revolutionized the way dental prostheses are designed and fabricated. Currently, different manufacturing methods can be adopted for obtaining these prostheses, including conventional and digital methods. [19]

Resins manufactured by the conventional method offer good cost- effectiveness and ease of fabrication; however, they fall short in terms of physical and mechanical properties. On the other hand, resins manufactured by the digital method have shown high quality, precision, and reduced errors during fabrication. [20]

Over the past 30 years, 3D printing and prototyping has gained popularity within the profession and among patients alike. It has provided comfort and better quality of restoration to dentists. Moreover, dental restorations, which are being produced through rapid prototyping, are more adaptive and faster in production compared to the restorations created by dental technicians. 3D printing has been used increasingly since the 1980s. [21] In 1983, Charles Hull printed, for the first time, a three-dimensional object. In prosthetic treatments, computerized scanning systems and 3D printing systems have come largely to replace traditional techniques for producing prosthetic works. [22]

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JCHR (2025) 15(6), 2128-2138 | ISSN:2251-6727

Alyami et al 2024 stated that the advent of 3D printing technology has revolutionized removable prosthodontics, offering novel materials for denture fabrication with enhanced customization and efficiency. However, the bonding between 3D-printed denture teeth and PMMA denture base resins remains a critical factor in ensuring the durability and clinical success of these prostheses. Surface treatment plays a crucial role in enhancing mechanical and chemical interlocking at the tooth-denture base interface. Surface treatments such as sandblasting and chemical applications, particularly methyl methacrylate (MMA), have been widely studied to improve shear bond strength by modifying the interfacial properties between denture teeth and bases. Sandblasting, a mechanical method, enhances surface roughness and promotes micromechanical interlocking, which is particularly beneficial for layered polymerized structures like 3D-printed resins. [23]

Most commonly used materials for 3D printed teeth were photopolymer resins, composite materials, PMMA, metals and ceramics. The most common material for 3D printed teeth is light-cured photopolymer resin, often methacrylate-based. These resins are favoured for their ability to be precisely shaped using stereolithography (SLA) or digital light processing (DLP) printers, offering high resolution and good surface finish. Methacrylate- based resins can be reinforced with fillers such as glass, hydroxyapatite (HAP), and porcelain to better mimic the mechanical properties of natural teeth, especially for educational typodonts and provisional restorations. Composite 3D printing involves adding fillers (e.g., glass flakes, hydroxyapatite, fluor-mica glass) to the resin matrix. This approach allows the mechanical properties such as hardness and elastic modulus to be tuned to closely match those of natural enamel and dentine. Adding 25 wt. % hydroxyapatite to a methacrylate resin can produce a cutting force similar to that of natural enamel, while glass flake or fluormica glass fillers can mimic dentine.

Poly methyl methacrylate (PMMA) is widely used due to its biocompatibility, affordability, and acceptable aesthetics. PMMA is common in denture bases and temporary crowns, and can be processed via both milling and 3D printing. PMMA composites with fillers improve impact strength and fracture resistance, though high filler content can make processing more difficult. For permanent dental prosthetics (e.g., crowns, bridges), selective laser sintering (SLS) and selective laser melting (SLM) are used to print with metals (such as cobalt-chromium alloys) and ceramics. These materials offer high strength and durability, suitable for long-term restorations.

The choice of material for 3D printed teeth is crucial and depends largely on the intended clinical application. In restorative and prosthetic dentistry, materials must meet strict requirements for biocompatibility, mechanical strength, aesthetics, and durability. Commonly used materials include metals (such as titanium and its alloys), ceramics (like zirconia and porcelain), and various polymers and composite resins. Titanium and its alloys are the gold standard for dental implants and abutments due to their excellent strength, corrosion resistance, and proven biocompatibility, making them ideal for long-term, load-bearing applications. Ceramics, particularly zirconia, are favoured for crowns, bridges, and veneers because they closely mimic the appearance of natural teeth while offering high wear resistance and strength. For temporary restorations, dentures, surgical guides, and anatomical models, photopolymer resins and PMMA (polymethyl methacrylate) are widely used. These materials are easy to process, customizable, and can be reinforced with fillers to enhance their mechanical properties.

In clinical practice, 3D printed dental materials have a broad range of applications. Custom titanium implants and abutments are used for tooth replacement, especially in cases with complex anatomical challenges. Ceramic materials are employed for both temporary and permanent crowns and bridges, providing patients with restorations that are both functional and aesthetically pleasing. Polymers and composite resins are commonly used for fabricating dentures, surgical guides, orthodontic appliances, and patient- specific anatomical models. These models are invaluable for treatment planning, surgical simulation, and patient education. Additionally, the field of regenerative dentistry is exploring the use of bioprinting with bioinks and living cells for tissue engineering and periodontal regeneration, although this is still largely experimental.

The relevance of these materials and their applications in modern dental practice is significant. 3D printing enables the production of highly customized, patient-specific restorations and devices, which improves fit, function, and aesthetics compared to traditional methods. The digital workflow streamlines the fabrication process, reducing turnaround times and allowing for rapid prototyping and adjustments. This leads to more predictable clinical outcomes and often reduces the need for extensive chairside modifications. Furthermore, 3D printing expands treatment options, making it possible to address complex cases that would be challenging with conventional techniques. It also enhances patient communication and education through the use of accurate anatomical models. Overall, the integration of 3D printed materials into dental practice has improved efficiency, expanded the scope of care, and contributed to better patient outcomes.

On the other hand, MMA application chemically etches the surface, facilitating molecular entanglement between the materials. Despite their individual merits, the efficacy of these treatments varies depending on the material properties of 3D-printed denture teeth and PMMA bases. Studies have shown that while sandblasting provides superior durability under thermal cycling conditions, MMA application is more effective for CAD/CAM-milled PMMA but less reliable for 3D-printed resins due to potential over-etching. [24][25]

Hence the current study evaluated and compared the effectiveness of these surface treatments on shear bond strength in an in vitro setting, contributing to the growing body of knowledge on optimizing bonding protocols for 3D- printed denture systems. The shear bond strength between 3D-printed denture teeth and acrylic (PMMA) denture bases is significantly influenced by surface treatments, with mechanical methods like sandblasting demonstrating superior efficacy compared to chemical or untreated surfaces.

Sandblasting (Al_2O_3 airborne-particle abrasion) emerges as the most effective method for 3D-printed denture teeth. This treatment increases surface roughness, enhancing mechanical interlocking with PMMA bases. Studies report shear bond strength values comparable to traditional heat- polymerized PMMA controls, even after 2000 thermal cycles simulating oral conditions.[26][27]

Similarly, Pereira Ak et al 2024 stated that sandblasted 3D-printed teeth achieved SBS of 12.3±1.7 MPa post-thermocycling, comparable to the control group in the thermal cycles and non-thermal cycled samples. Hence, Sandblasting is recommended to increase the bond strength between the tooth and denture bases.[28] Tanaka A et al 2023, evaluated various surface treatments on flexural bond strength of repaired denture base resins produced by digital and conventional methods. The test samples were grinding with silicon carbide (SC), sandblasting with Al2O3 (SB), Er:YAG laser (L), plasma (P) and negative control (NC) group (no treatment). The surface treatments applied to the CAD/CAM and heat-polymerized groups did not result in a statistically significant difference in the repair flexural strength values compared to the NC groups ($p > 0.05$). Laser surface treatment has been the most powerful repair method for 3D printing technique. Surface treatments led to similar repair flexural strengths to untreated groups for CAD/CAM milled and heat-polymerized test samples. The current study finding was contrast to the above study.[29]

In contrast, an invitro study conducted by Nour alhouda Alhomsi et al, evaluated various surface treatments on the shear bond strength of a CAD

/CAM PMMA teeth to the heat -polymerized acrylic denture base. The study finding stated that the sandblasting and perpendicular grooves showed no significant difference in the shear bond strength ($P = 0.548$ and 0.061; respectively) and PMMA plus Sandblasting groups showed the weakest bonding.[30] Also, Kwanwong Boonpitak et al. (2022) examined Air abrasion: Sandblasting with Aluminium oxide particles, Methyl methacrylate (MMA): Monomer application for 30 seconds, MMA + heat post-curing: MMA application followed by heat polymerization, Combination: Air abrasion followed by MMA. Shear bond strength was measured using a universal testing machine, and failure modes (adhesive, cohesive, or mixed) were analysed via stereomicroscopy. The authors concluded that combining MMA application with heat polymerization significantly enhanced interfacial bonding in 3D-printed dentures, offering a clinically viable method to improve bond strength compared to untreated or single-treatment approaches. These findings align with broader research emphasizing surface modifications such as mechanical abrasion or chemical activation to optimize adhesion in digitally fabricated prosthetics. [31]

Chemical treatment Methyl methacrylate (MMA) monomer application, while effective for CAD/CAM PMMA teeth, shows inconsistent results for 3D- printed resins. Although MMA partially dissolves the surface to enable molecular bonding, it underperforms compared to sandblasting in 3D-printed groups due to material composition differences. [32]

There is a statistically significant difference in shear bond strength between mechanically treated, chemically treated, and untreated 3D printed denture teeth when bonded to acrylic denture base resins. The current study rejects the null hypothesis and accepts the alternate hypothesis.

There are some limitations for the study such as the current study was conducted under controlled laboratory conditions, which may not fully replicate the dynamic oral environment. Factors such as saliva, masticatory forces, and temperature fluctuations could affect the bond strength differently in vivo. The absence of biological fluids and mechanical stresses in the in vitro setup might underestimate the challenges faced by the bond in clinical settings. The properties of 3D-printed resins can vary significantly based on the printing technology, resin composition, and post-processing techniques. This variability could influence the effectiveness of surface treatments and bond strength outcomes. The study might not account for all types of 3D- printed materials available, limiting its generalizability across different resin formulations. Addressing these limitations would require further research, including clinical trials and studies on material variability, to ensure that the findings are robust and applicable across diverse clinical scenarios. Additionally, further research is required to optimize surface treatment protocols specifically for various brands and compositions of 3D printed resins, as the bonding potential may vary depending on the material formulation and printing technology used. With the increasing use of 3D printed denture teeth, ensuring a reliable bond with the denture base is critical to prevent tooth debonding, a common cause of prosthesis failure. The findings of this study provide valuable guidance for clinicians and dental technicians, suggesting that surface treatment particularly a combination of sandblasting and monomer application is essential to achieving adequate bond strength and long-term prosthesis integrity

Conclusion:

Within the limitations of this in-vitro study, both mechanical (sandblasting) and chemical (MMA application) surface treatments significantly enhanced the shear bond strength between 3D-printed denture teeth and PMMA denture base resin. Sandblasting demonstrated superior bond strength compared to MMA treatment, indicating that mechanical modification provides a more reliable adhesion interface. These findings suggest that incorporating appropriate surface pretreatments may improve the longevity and clinical performance of removable prostheses fabricated with 3D-printed denture teeth.

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