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# Effect of Cyanoacrylate Adhesives on Shear Bond Strength Between 3D-Printed Denture Bases and 3D-Printed Teeth

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**ABSTRACT**

**Introduction:** The advent of 3D printing in prosthodontics has improved denture fabrication by offering greater precision and customization. However, achieving a strong bond between 3D-printed denture bases and teeth remains a challenge, affecting prosthesis longevity. Cyanoacrylate adhesives, known for their rapid bonding properties, may offer an alternative to conventional bonding techniques. This study evaluates and compares the shear bond strength of ethyl, n-butyl, and iso-amyl cyanoacrylate adhesives in bonding 3D-printed denture bases and teeth.

**Methodology:** 3D-printed denture base and tooth specimens were fabricated according to ISO-TS 19736 standardization and were divided into control printing resin, ethyl cyanoacrylate, n-butyl cyanoacrylate, and iso-amyl cyanoacrylate groups. Bonding protocol followed the manufacturer's instructions. Shear bond strength was measured using a universal testing machine, and failure modes were classified as adhesive, cohesive, or mixed failures. Statistical analysis was performed using one-way ANOVA and Tukey's post-hoc test.

**Results:** A statistically significant difference in shear bond strength was observed among the groups. Iso-amyl cyanoacrylate exhibited the highest bond strength, followed by n-butyl cyanoacrylate and the control, while ethyl cyanoacrylate showed the weakest bond. The control and ethyl cyanoacrylate groups exhibited adhesive failures, while n-butyl and iso-amyl cyanoacrylate displayed mixed and cohesive failures, indicating stronger bonds.

**Conclusion:** Iso-amyl and n-butyl cyanoacrylate significantly improve the shear bond strength of 3D-printed dentures compared to conventional 3D-printing resin and ethyl cyanoacrylate. Iso-amyl cyanoacrylate shows the most promise for clinical use, warranting further research on its long-term performance.

***Keywords:*** *3D printed dentures, CAD/CAM, cyanoacrylate, adhesive, shear bond strength*

## 1. INTRODUCTION

Traditionally, heat-polymerized polymethyl methacrylate (PMMA) has been the gold standard for fabricating denture bases due to its ease of manipulation, biocompatibility, and cost-effectiveness. However, this conventional technique presents several challenges, particularly in achieving a strong and durable bond between denture bases and artificial teeth. With advancements in digital dentistry, new fabrication methods, such as computer-aided design/computer-aided manufacturing (CAD/CAM) milling and three-dimensional (3D) printing, have emerged as promising alternatives to traditional heat-polymerization techniques.(1,2) The advent of additive manufacturing technologies has revolutionized various fields, including medicine and dentistry, by offering unprecedented precision, efficiency, and customization.(3) In dentistry, 3D printing is increasingly used to fabricate prosthetic components such as denture bases and artificial teeth.(4,5) Compared to traditional techniques, including heat-polymerized acrylic resins and subtractive CAD/CAM milling, 3D printing allows for a more streamlined workflow and enables the production of intricate geometries that closely match patient anatomy.(6–8) Despite these advantages, certain limitations associated with 3D printing in prosthodontics, such as mechanical properties and interfacial bond strength between components, continue to pose challenges for clinical application.(9,10)

The bond strength between the denture base and artificial teeth is a critical factor influencing the success and longevity of removable dentures. During mastication, dentures experience significant occlusal forces, subjecting the bond to stresses that can lead to mechanical failures if the bond strength is insufficient.(11,12) In conventionally fabricated heat-cured dentures, where both the base and teeth are often made from similar materials, a chemical bond results and the bonding is typically reliable. However, studies have reported that debonding of denture teeth is a common clinical problem, often leading to failure of the prosthesis and the need for repairs or replacements.(13) According to studies, 30% of all denture repairs are caused by debonding of prefabricated teeth.(14) Moreover, with 3D-printed dentures, the use of separate materials for the base and teeth furthermore results in reduced bond strength. Studies have shown that the bond strength between 3D-printed resins is generally inferior to that of traditional acrylic dentures, necessitating the development of improved bonding agents and techniques.(4,11–13)

Cyanoacrylate adhesives, commonly referred to as superglues, have been extensively used in medical, industrial, and household applications for their rapid bonding capabilities, strong adhesion, and ease of use.(15,16) These adhesives polymerize quickly upon exposure to moisture, forming a durable and rigid bond. In dentistry, cyanoacrylate adhesives have primarily been explored periodontal and tissue adhesive applications, but their potential in prosthodontics remains underutilized. Among the various formulations of cyanoacrylate adhesives, medical-grade types such as n-butyl, iso-amyl, and 2-octyl cyanoacrylate are particularly promising due to their enhanced flexibility, biocompatibility, and superior mechanical properties compared to the more commonly used ethyl cyanoacrylate.(16,17) These differences in chemical structure can significantly affect the performance of the adhesive under intraoral conditions. Ethyl cyanoacrylate is the most widely used, readily available variant of cyanoacrylate adhesives known for its high initial bonding strength. But, it tends to exhibit brittle failure when subjected to dynamic loading, such as the repetitive forces experienced during mastication.(15) Additionally, its degradation products have been shown to exhibit limited biocompatibility, making it industrial grade.(18) On the other hand, medical-grade cyanoacrylates such as n-butyl and 2-octyl cyanoacrylate are designed to address these limitations.(19,20) These adhesives offer improved flexibility and toughness, reducing the likelihood of brittle fractures. Iso-amyl cyanoacrylate, a relatively newer formulation, combines high strength with flexibility, making it a potential candidate for durable bonding applications in 3D-printed dental prosthetics.(21)

Despite the promising properties of cyanoacrylate adhesives, there is a lack of comprehensive studies evaluating their performance in bonding 3D-printed denture bases to artificial teeth. Given the unique challenges posed by the use of 3D printing in prosthodontics, such as variations in material chemistry and composition, it is essential to investigate alternative bonding agents that can improve shear bond strength while maintaining clinical feasibility. The objective of this study was to evaluate and compare the shear bond strength between 3D-printed denture bases and artificial teeth using different formulations of cyanoacrylate adhesives, namely ethyl, n-butyl and iso-amyl cyanoacrylate with a control group with the same 3D printing resin was also included to establish a baseline for comparison and to identify the most effective adhesive for bonding 3D-printed prosthetic components. The study hypothesized that medical-grade cyanoacrylate adhesives would demonstrate superior shear bond strength compared to ethyl cyanoacrylate and the printing resin that is usually being used according to previous literature.

## 2. METHODOLOGY

Four groups were established: four experimental groups using different types of cyanoacrylate adhesives—ethyl (Anabond Cyano, Anabond Limited, India), n-butyl (Endocryl, Samarth Life Sciences Pvt. Ltd., India) and iso-amyl cyanoacrylate (Amcrylate, Concord Medicals, India)—and a control group with the same photo-curable light resin itself. The study used 3D-printed samples of denture bases and artificial teeth created from photo-curable acrylic resins NextDent Denture 3D for bases and NextDent C&B for teeth (Vertex-Dental B.V., Netherlands). Sample size was calculated to be 32 using GPower 3.0 software according to a pilot study performed. Sample preparation and testing methodology was standardized according to the ISO/TS 19736 standard for shear bond strength testing. The samples were numbered and were randomly allotted to either one of the groups using Random Allocation software 2.0. The cylinders with the socket simulated the denture base into which the denture teeth can be placed. Each adhesive was applied according to the manufacturer's guidelines, with a thin layer applied to the bonding surface of the denture base. The artificial tooth was then positioned with firm digital pressure to eliminate air pockets and ensure optimal contact. Shear bond strength testing was performed using a universal testing machine, which applied a perpendicular force with a crosshead speed to 0.5cm/second to the bonded surface until failure of the sample occurred as seen in Figure 1. The maximum force at the point of bond failure was recorded for each sample in megapascals (MPa).

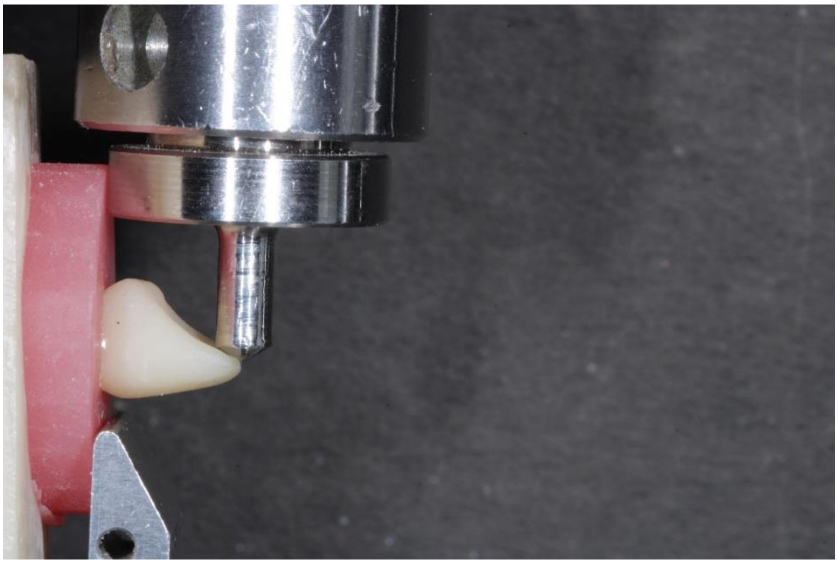

**Figure 1: Shear bond strength evaluation using Universal Testing Machine**

The type of bond failure was classified into adhesive, cohesive and mixed failures. Adhesive failure occurred between the interfaces of 3D-printed artificial acrylic tooth and 3D-printed denture base samples. Cohesive failure occurred within either of 3D-printed artificial acrylic tooth or 3-D printed denture base samples. Mixed failure was a combination of both the failures. 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 software. Shapiro-Wilk's test of normality showed that the data were normally distributed. Hence, one-way ANOVA was conducted to compare mean bond strengths between groups, followed by Tukey's post-hoc multiple comparisons analysis to determine specific differences among the shear bond strengths.

## 3. RESULTS

The study found significant differences in shear bond strength between the different cyanoacrylate formulations and the control group ($p<0.001$). Among the cyanoacrylate adhesives, iso-amyl cyanoacrylate demonstrated the highest average shear bond strength (2.960±0.053 MPa), followed by n-butyl (1.844±0.190 MPa), and resin (1.696±0.034 MPa) as seen in Figure 2. Ethyl cyanoacrylate exhibited the lowest bond strength (1.370±0.046 MPa), highlighting the necessity of a medical grade adhesive agent for reliable bonding in 3D-printed dentures.

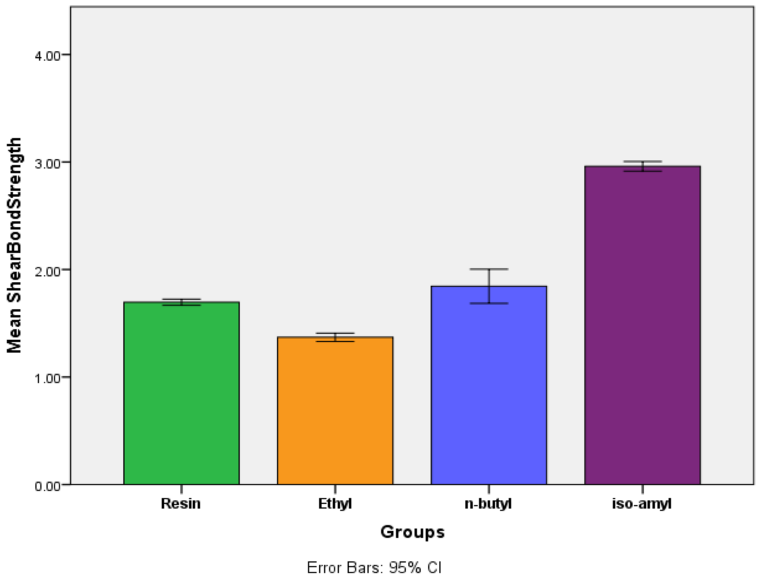


**Figure 2: Shear bond strength evaluation**

The mode of bond failure was reported with all the samples of control group and ethyl cyanoacrylate group showing adhesive failures. In the n-butyl group, 3 showed adhesive failure, 4 showed mixed failure, whereas 1 showed cohesive failure. In the iso-amyl group, 1 sample showed adhesive failure, whereas 3 and 4 samples showed mixed and cohesive failures respectively.

## 4. DISCUSSION

The study's findings support the alternate hypothesis that medical-grade cyanoacrylates can improve the shear bond strength of 3D-printed dentures, and reduce the likelihood of prosthetic failure caused by debonding of the teeth. The results of this study demonstrate that the choice of cyanoacrylate adhesive significantly impacts the shear bond strength between 3D-printed denture bases and teeth.

Iso-amyl cyanoacrylate showed almost double the shear bond strength as compared to that of the printing resin that is most commonly being used ($p<0.000$). The superior performance of iso-amyl cyanoacrylate may be attributed to its balanced mechanical properties, which allow it to provide strong adhesion without compromising flexibility. These properties are advantageous in the oral environment, where bonded components are subjected to complex masticatory forces, including compressive and tensile stresses. This combination may position it as the most promising candidate among the adhesives tested for clinical use in 3D-printed dentures. N-butyl cyanoacrylate also displays a statistically significantly stronger bond than the printing resin, which can help absorb masticatory forces and can also be used as an adhesive for 3D printed dentures. However, the mean difference between the two groups was only 0.148 MPa ($p=0.036$). In contrast, ethyl cyanoacrylate, though most commonly used and effective in many non-biological applications, showed the least shear bond strength, thereby showing limited applicability in dental bonding due to its low biocompatibility and brittle nature. This aligns with findings from previous studies, which indicate that ethyl cyanoacrylate's degradation products may be toxic and unsuitable for long-term intraoral use. This adhesive was not a medical-grade cyanoacrylate, and its poor biocompatibility and weaker bond strength limits its clinical suitability for denture bonding.

The mode of bond failure showed all adhesive failures in the lower bond strength groups (control and ethyl), while mixed and cohesive failures were more common in samples with higher bond strengths, such as those bonded with iso-amyl cyanoacrylate. It can be deduced that the mixed and cohesive failures occur wherein the bond strength of the adhesive outperforms the molecular bond strengths of the substrate itself.(22)

These results suggest that medical-grade cyanoacrylates, particularly iso-amyl and n-butyl cyanoacrylate, could provide enhanced bonding strength and resilience, potentially extending the functional lifespan of 3D-printed dentures. In the knowledge of the authors, this is the first study to evaluate the use of medical grade cyanoacrylates for luting printed denture bases and teeth, hence, no prior comparison could be established. This in-vitro analysis can be marked as the initiation for more research to be done in this field. Additional research is needed to evaluate the effects of thermocycling, aging, and repeated loading on the bond strength and longevity of cyanoacrylate-bonded 3D-printed dentures. The development and testing of new adhesive agents specifically designed for 3D-printed dental materials may further optimize bond strength and improve the longevity of 3D-printed dentures.

## 5. CONCLUSION

This study demonstrated that cyanoacrylate adhesives, particularly medical-grade formulations, are effective in enhancing the shear bond strength between 3D-printed denture bases and teeth. Iso-amyl cyanoacrylate exhibited the highest bond strength and most favorable failure modes, making it and N-butyl cyanoacrylate as promising choices for clinical applications where durability and resilience are required.

**Table 1: Statistical analysis using one-way ANOVA and Tukey's multiple comparisons test**

| Groups | Groups | Mean Difference | Std. Error | 95% Confidence Interval | | p value |
|---|---|---|---|---|---|---|
| | | | | Lower | Upper | |
| Resin | Ethyl | 0.32625* | 0.05154 | 0.1855 | 0.4670 | 0.000* |
| | n-butyl | -0.14813* | 0.05154 | -0.2889 | -0.0074 | 0.036* |

| | | | | | | |
|---|---|---|---|---|---|---|
| | iso-amyl | -1.26375* | 0.05154 | -1.4045 | -1.1230 | 0.000* |
| Ethyl | Resin | -0.32625* | 0.05154 | -0.4670 | -0.1855 | 0.000* |
| | n-butyl | -0.47438* | 0.05154 | -0.6151 | -0.3336 | 0.000* |
| | iso-amyl | -1.59000* | 0.05154 | -1.7307 | -1.4493 | 0.000* |
| n-butyl | Resin | .14813* | 0.05154 | 0.0074 | 0.2889 | 0.036* |
| | Ethyl | 0.47438* | 0.05154 | 0.3336 | .06151 | 0.000* |
| | iso-amyl | -1.11562* | 0.05154 | -1.2564 | -0.9749 | 0.000* |
| iso-amyl | Resin | 1.26375* | 0.05154 | 1.1230 | 1.4045 | 0.000* |
| | Ethyl | 1.59000* | 0.05154 | 1.4493 | 1.7307 | 0.000* |
| | n-butyl | 1.11562* | 0.05154 | 0.9749 | 1.2564 | 0.000* |

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