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Influence of chemical surface treatment on bond strength of acrylic teeth to conventional and nano-silica reinforced denture base resin: An in vitro study

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ABSTRACT

Background: Debonding of acrylic denture teeth from denture base resin remains a frequent cause of prosthesis failure. Chemical surface modification of the ridge lap area and reinforcement of polymethyl methacrylate (PMMA) with nano silica particles have been proposed to enhance tooth-resin adhesion.

Aim: To evaluate and compare the effect of chemical surface modification using dichloromethane, ethyl acetate, cyanoacrylate and acetone on the shear bond strength of acrylic denture teeth bonded to unreinforced PMMA and nano silica ($nSiO_2$) reinforced PMMA denture base resin.

Materials and Methods: 50 standardized samples were fabricated and divided into two main groups based on denture base resin: conventional PMMA and $nSiO_2$ reinforced PMMA (2 wt%). Each group was further subdivided into five subgroups according to ridge lap surface treatment: control (no treatment), dichloromethane, ethyl acetate, cyanoacrylate and acetone. Heat-cure PMMA was processed using a conventional compression molding technique. All samples were stored in water for 7 days before testing. Shear bond strength was evaluated using a universal testing machine at a crosshead speed of 1 mm/min. Data were analysed using One-way ANOVA and post hoc tests ($p \leq 0.05$).

Results: Chemical surface treatment significantly influenced bond strength in both resin groups ($p < 0.001$). Dichloromethane showed the highest bond strength for conventional PMMA (29.26 ± 0.63 MPa) and $nSiO_2$ reinforced PMMA (31.88 ± 0.59 MPa). Cyanoacrylate demonstrated the lowest values in both groups. Nano-silica reinforced PMMA exhibited consistently higher bond strength than unreinforced PMMA across all surface treatments.

Conclusion: Chemical surface modification enhances the bond strength of acrylic denture teeth to denture base resin with dichloromethane being the most effective agent. Nano-silica reinforcement further improves tooth-resin adhesion. The combination of dichloromethane surface treatment and $nSiO_2$ reinforced PMMA provides the highest bond strength and may improve the clinical longevity of complete dentures.

KEY WORDS

Acrylic denture teeth; Nano silica reinforcement; PMMA; Shear bond strength; Surface treatment

ARTICLE HISTORY

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Introduction

Replacement of missing teeth is a fundamental objective of prosthodontic therapy, aimed at restoring mastication, phonetics, facial esthetics and psychological well-being. Tooth loss, particularly in the anterior region can significantly affect self-image and social confidence [1]. Progressive alveolar bone resorption following tooth loss alters facial contours, reduces occlusal vertical dimension and compromises oral function making prosthodontic rehabilitation essential [2].

Despite advancements in fixed and implant-supported prostheses, removable complete dentures remain a widely used and cost-effective treatment option [3]. Polymethyl methacrylate (PMMA) remains the most used denture base material due to its favourable esthetics, ease of processing and acceptable mechanical properties [4]. However, debonding of acrylic denture teeth from the denture base resin is a common clinical complication that adversely affects prosthesis longevity and patient satisfaction [5,6].

Various approaches have been suggested to enhance tooth-resin bonding, including mechanical modifications, chemical surface treatments, and material reinforcement [7]. Chemical agents such as dichloromethane, ethyl acetate, cyanoacrylate, and acetone modify the ridge-lap surface by softening or swelling the acrylic tooth surface, thereby promoting interpenetration and chemical bonding with the denture base resin [8,9]. Reinforcement of PMMA with nano-silica ($nSiO_2$) particles has been reported to improve mechanical properties, fracture resistance and interfacial bonding [10-12].

The present in-vitro study was undertaken to comparatively evaluate the effect of different chemical surface modification agents on the shear bond strength of acrylic denture teeth bonded to unreinforced PMMA and $nSiO_2$ reinforced PMMA denture base resin.

Materials and Methods

A total of 50 samples were included in the study with 25 samples in each main group (conventional PMMA and nano-silica reinforced PMMA). Each main group was further subdivided into five subgroups (n = 5 per subgroup) based on the surface treatment protocol: control, dichloromethane (Merck, Germany), ethyl acetate (Merck, Germany), cyanoacrylate (Fevikwik, Pidilite, India), and acetone (Merck, Germany).

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Randomization was performed using a computer-generated random allocation sequence to assign samples into respective subgroups, thereby minimising selection bias. All samples were coded numerically to conceal group identity. Blinding was implemented during the testing phase, wherein the operator conducting the shear bond strength testing using the universal testing machine was unaware of the group allocation. This ensured objectivity and reduced operator bias during data acquisition (Figure 1).

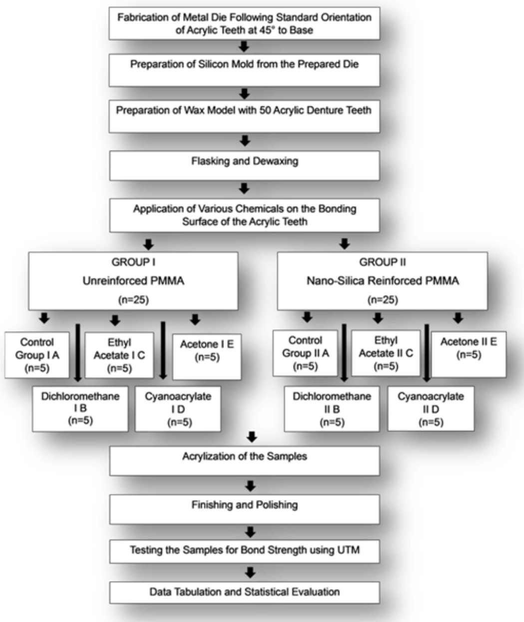

Figure 1. Flowchart presenting the study design.

Mold and pattern preparation

A custom-made cobalt-chromium master die (3.7 × 1.2 × 1.2 cm) was fabricated to ensure uniform sample dimensions. Acrylic denture teeth (DPI, India) were positioned at a standardized 45° angulation. A master mold was prepared using polyvinyl siloxane impression material (Zhermack, Italy) from which wax patterns with embedded acrylic teeth were obtained. The wax was allowed to cool and solidify at room temperature and then wax samples were subsequently retrieved from the mold without distortion (Figure 2).

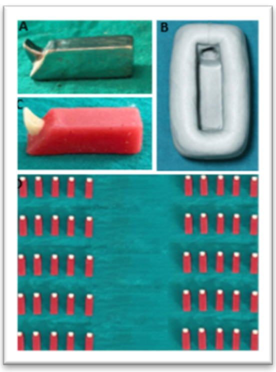

Figure 2. (A) Custom Made Cobalt-Chromium Master Die (B) Master Mold (C) Wax Pattern (D) Wax Pattern Samples.

Flasking was carried out using Type II dental plaster (Neelkanth, India) following conventional laboratory procedures. Dewaxing was performed by immersing the flasks in boiling water to eliminate wax and expose the contact surfaces of the acrylic teeth (Figure 3)

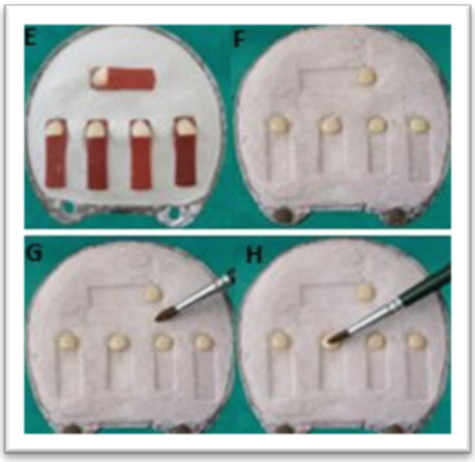

Figure 3. (E,F) Flasking and Dewaxing of the Wax Samples (G,H) Application of Separating Medium followed by Application of Chemicals.

Preparation of nano-silica reinforced PMMA

The nano-silica ($nSiO_2$) particles used in this study had an average particle size ranging from 20–40 nm. A concentration of 2 wt% nano-silica was incorporated into the PMMA polymer powder. To ensure uniform dispersion, the nanoparticles were first weighed using an analytical balance and gradually added to the PMMA powder.

The mixture was homogenized using a mechanical mixing method followed by manual spatulation for approximately 10 minutes to achieve even distribution. To minimize agglomeration and clustering of nanoparticles, the powder mixture was sieved and blended in a dry environment before monomer addition. Care was taken to ensure that the nanoparticles were uniformly distributed within the polymer matrix before mixing with monomer, thereby improving interfacial bonding and mechanical properties.

Surface treatment of acrylic denture teeth

All surface treatment procedures were standardized to ensure reproducibility. The ridge-lap surface of each acrylic denture tooth was cleaned and dried before chemical application. Analytical grade chemicals were used: dichloromethane (99.8%), ethyl acetate (99.5%), and acetone (99.5%), while cyanoacrylate adhesive was used as supplied commercially.

Each chemical agent was applied using a microbrush in a uniform thin layer over the ridge-lap surface for a standardized duration of 60 seconds. Care was taken to cover the entire bonding surface without pooling. Following application, the treated surfaces were allowed to air-dry for 30-60 seconds to permit evaporation of volatile solvents before packing the denture base resin.

All procedures were performed by a single operator under controlled environmental conditions to eliminate variability. The application time, quantity and method was kept constant for all samples to ensure standardization across groups.

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Test samples processing

Denture base samples were fabricated using heat-cure PMMA resin. Both unreinforced PMMA and nano-silica ($nSiO_2$) reinforced PMMA (2 wt%) were prepared. The PMMA powder and monomer were mixed in a 3:1 ratio and packed at the dough stage using a conventional compression molding technique. Polymerization was carried out using a standardized long curing cycle followed by terminal boiling. After gradual cooling, the samples were retrieved, finished and polished using standard laboratory procedures (Figure 4).

Figure 4. (I) Conventional and Nano-Silica Reinforced PMMA Resins (J) Samples kept in Water for Ageing (K) Test Samples in their Respective Groups (L) Shear Load Application using Universal Testing Machine.

Storage of samples

All samples were immersed in water for 7 days before testing to simulate intraoral conditions and allow water sorption equilibrium.

Test For evaluation

Shear bond strength between the acrylic denture tooth and denture base resin was evaluated using a universal testing machine (Instron, USA). A controlled load was applied at a crosshead speed of 1 mm/min until bond failure occurred. The load at failure was recorded in Newtons and shear bond strength was calculated in megapascals (MPa) by dividing the failure load by the bonded surface area (Figure 3). The obtained data were statistically analyzed using One-way ANOVA followed by post-hoc tests with the level of significance set at $p \leq 0.05$.

Results

Failure mode analysis was performed by visually examining the deboned surfaces of samples following shear bond testing. Failures were categorized as adhesive (failure at the tooth-resin interface), cohesive (failure within the denture base resin or tooth), or mixed (combination of adhesive and cohesive failure).

The control and cyanoacrylate groups predominantly exhibited adhesive failures, indicating weaker interfacial bonding. In contrast, dichloromethane-treated groups showed a higher incidence of mixed and cohesive failures, suggesting stronger interfacial adhesion and improved stress distribution. Nano-silica reinforced groups demonstrated increased cohesive failures within the resin, reflecting enhanced internal strength of the denture base material.

The interfacial shear bond strength of acrylic denture teeth bonded to conventional PMMA and $nSiO_2$ reinforced PMMA was significantly influenced by chemical surface treatment ($p < 0.001$). For conventional PMMA, dichloromethane showed the highest load at failure (574.0 ± 11.94 N) and shear bond strength (29.26 ± 0.63 MPa) followed by ethyl acetate (510.0 ± 7.91 N; 26.00 ± 0.38 MPa) and acetone (480.0 ± 7.91 N; 24.46 ± 0.43 MPa). The control group recorded 421.0 ± 7.55 N and 21.44 ± 0.37 MPa while cyanoacrylate showed the lowest values (370.0 ± 7.91 N; 18.86 ± 0.43 MPa).

For $nSiO_2$ reinforced PMMA, dichloromethane again demonstrated the highest load at failure (626.0 ± 11.94 N) and bond strength (31.88 ± 0.59 MPa) followed by ethyl acetate (550.0 ± 7.91 N; 28.00 ± 0.38 MPa) and acetone (520.0 ± 7.91 N; 26.52 ± 0.40 MPa). The control group showed 448.4 ± 5.94 N and 22.84 ± 0.30 MPa while cyanoacrylate recorded the lowest values (400.0 ± 7.91 N; 20.38 ± 0.40 MPa). The bonded area remained constant at 19.63 mm² in all groups. Overall, $nSiO_2$ reinforced PMMA exhibited higher bond strength than conventional PMMA with dichloromethane being the most effective and cyanoacrylate the least effective surface treatment (Table 1 and Figure 5). Hence, dichloromethane surface treatment combined with $nSiO_2$ reinforced PMMA produced the highest and most clinically reliable bond strength.

Table 1. Evaluation of bond strength of PMMA and nSiO2 reinforced denture base resin following surface treatment.

Parameters	**Chemical Treatment**	**PMMA Denture Base Resin**		**Nano-Silica Reinforced Denture Base Resin**	
		Mean	Std. Deviation	Mean	Std. Deviation
Load at Failure (N)	Control	421	7.549	448	5.941
	Dichloromethane	574	11.937	626	11.937
	Ethyl Acetate	510	7.905	550	7.905
	Cyanoacrylate	370	7.905	400	7.905
	Acetone	480	7.905	520	7.905
Bonded Area (mm^2)	Control	19.6	0	19.6	0
	Dichloromethane	19.6	0	19.6	0
	Ethyl Acetate	19.6	0	19.6	0
	Cyanoacrylate	19.6	0	19.6	0
	Acetone	19.6	0	19.6	0

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Shear Bond Strength (MPa)	Control	21.4	0.371	22.8	0.304
	Dichloromethane	29.3	0.634	31.9	0.589
	Ethyl Acetate	26	0.38	28	0.38
	Cyanoacrylate	18.9	0.427	20.4	0.396
	Acetone	24.5	0.427	26.5	0.396

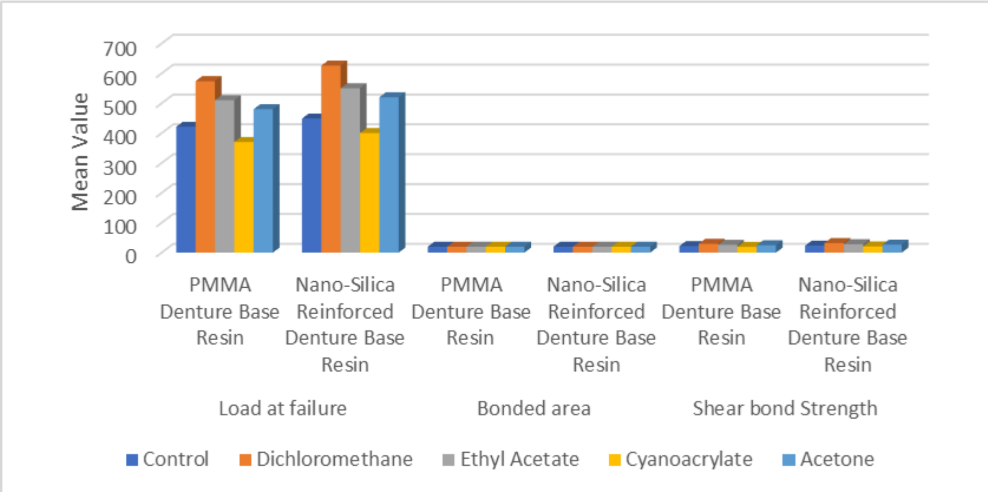

Figure 5. Mean Comparison of Shear Bond Strength of PMMA and $nSiO_2$ Reinforced PMMA following Surface Treatment.

Discussion

The results of the present study demonstrate that chemical surface modification significantly enhances the bond strength between acrylic denture teeth and denture base resin, which is consistent with previous findings in the literature [13,23]. Untreated specimens exhibited lower bond strength due to the highly polymerized and smooth ridge-lap surface of acrylic teeth, which limits chemical interaction and mechanical interlocking with the denture base resin [5,6].

The improvement in bond strength observed with chemical surface treatments can be explained by the formation of an interpenetrating polymer network (IPN) at the tooth-resin interface. Solvent-based agents such as dichloromethane, ethyl acetate, and acetone partially dissolve or swell the acrylic tooth surface, allowing diffusion of methyl methacrylate monomer into the tooth structure during polymerization. This results in enhanced chemical bonding and micromechanical retention [8,9,14].

Among the tested agents, dichloromethane demonstrated the highest bond strength in both conventional and nano-silica reinforced PMMA groups. This can be attributed to its strong solvent action on PMMA, which promotes deeper monomer penetration and superior interfacial adhesion. Similar findings have been reported by Schneider et al. and Kim and Watts, who observed improved bond strength following dichloromethane surface treatment [14,15]. Ethyl acetate and acetone showed moderate improvements due to comparatively lower solvent efficacy, whereas cyanoacrylate exhibited the lowest bond strength. The inferior performance of cyanoacrylate may be due to the formation of a superficial adhesive layer that does not facilitate monomer diffusion or chemical interlocking [16,17].

Failure mode analysis further supported these findings. Control and cyanoacrylate-treated groups predominantly showed adhesive failures, indicating weak interfacial bonding. In contrast, dichloromethane-treated groups exhibited more mixed and cohesive failures, suggesting stronger adhesion and improved stress distribution at the interface. These observations are consistent with studies evaluating denture tooth–resin bonding behaviour under different surface treatments [13,23].

Nano-silica reinforced PMMA demonstrated consistently higher bond strength than conventional PMMA across all surface treatment groups. This improvement can be attributed to enhanced mechanical properties, increased surface energy, and improved stress transfer at the tooth–resin interface [10-12,21]. The incorporation of nano-sized fillers increases the effective surface area and promotes better interaction between the resin matrix and denture tooth, thereby enhancing adhesion.

Nanoparticles also contribute to crack deflection, reduced polymerization shrinkage, and improved load distribution within the resin matrix, which further strengthens the bond [22]. The role of nanofillers in improving the mechanical and bonding properties of PMMA denture base materials was emphasized, supporting the findings of the present study [21,22].

Recent systematic reviews and studies have highlighted the growing importance of nanotechnology and advanced surface treatments in improving denture base performance. Ahmed and Ebrahim reported that chemical surface treatments significantly improve bond strength, particularly when solvent-based agents are used [23]. Similarly, Shibayama et al. demonstrated that appropriate surface modification enhances the durability of the tooth–resin interface [24]. Advances in

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denture base materials, including the use of nanofillers and modified polymers, have been shown to improve both mechanical properties and interfacial bonding [25].

The synergistic effect observed in this study with the combination of dichloromethane surface treatment and nano-silica reinforcement indicates that both surface modification and material enhancement play a critical role in optimizing bond strength. This combination provides improved wettability, enhanced chemical interaction, and superior stress distribution, resulting in the highest bond strength values.

Future research should focus on evaluating the long-term durability of these modifications under simulated oral conditions, including thermocycling, fatigue loading, and aging. Additionally, advanced surface modification techniques such as laser treatment, plasma treatment, and CAD/CAM-based denture fabrication may further enhance bonding performance and clinical outcomes.

Limitations

This study has certain limitations inherent to in-vitro experimental designs. The testing conditions do not fully replicate the complex oral environment, where factors such as thermal fluctuations, masticatory forces, saliva, and microbial activity influence material behaviour. Thermocycling was not performed, which could have simulated temperature variations and their effect on bond degradation.

Fatigue loading and long-term ageing protocols were not included, which limits the ability to predict clinical longevity under repeated functional stresses. Additionally, water storage for 7 days may not adequately represent long-term water sorption and hydrolytic degradation.

Failure mode analysis was performed macroscopically without advanced microscopic evaluation such as scanning electron microscopy (SEM) which could have provided more detailed insights into interfacial characteristics. Further in-vivo and long-term clinical studies are required to validate these findings and assess their applicability in real clinical conditions.

Conclusion

Chemical surface treatment improved the bond strength of conventional PMMA to acrylic teeth; dichloromethane was most effective, followed by ethyl acetate and acetone; cyanoacrylate was least effective. Nano-silica reinforced PMMA also showed higher bond strength with surface treatment; dichloromethane was superior, ethyl acetate and acetone were intermediate and cyanoacrylate was minimal. Intragroup comparison showed nano-silica reinforced PMMA consistently had higher bond strength than unreinforced PMMA; dichloromethane-treated $nSiO_2$ reinforced PMMA had the maximum strength. Overall, Surface treatment, especially with dichloromethane and nano-reinforcement, synergistically improve tooth-resin adhesion, enhance denture retention and durability. These results highlight the clinical advantage of combining surface treatment and nano-reinforcement for durable denture bonding.

Clinical Significance

Chemical surface treatment is essential for denture fabrication. Dichloromethane is the most effective with ethyl acetate and cyanoacrylate as alternatives and nano-silica reinforced PMMA can further enhance prosthesis durability.

Disclosure Statement

The author does not have conflict of interest in this research.

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