Comparative Evaluation of the Effect of Surface Treatments on The Shear Bond Strength between Acrylic Denture Teeth and Denture Base Resin – Three Dimensional Study

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Abstract

Purpose of study: The purpose of this study was to comparatively evaluate the effect of various surface treatments on the shear bond strength between acrylic denture teeth and polymethylmethacrylate denture base resin (PMMA) after thermocycling and to correlate the results with 3-D surface texture analysis.

Materials and Methods: A total of forty maxillary left central incisor denture teeth of similar shade and size were selected and divided into four groups of ten each based on the method of surface treatment rendered to the ridge lap area and these groups were designated as Group I, II, III and IV. Group I denture teeth were untreated, Group II denture teeth were sandblasted, Group III denture teeth were treated with chemical bonding agent and Group IV denture teeth were laser irradiated on the ridge lap area. One representative denture tooth from each group was subjected to 3-D surface texture analysis. Rectangular wax specimens along with the denture teeth were processed with the heat cure PMMA resin by injection molded technique. All the processed test samples were subjected to thermocycling and later tested for shear bond strength in universal testing machine. The basic values of shear bond strength of all test samples of four groups were tabulated and subjected for statistical analysis. The data were analysed with One way ANOVA and Tukey’s HSD analysis.

Results: The chemical bonding agent treated samples showed the highest mean shear bond strength (42.44Mpa) followed by laser irradiated samples (35.71 Mpa) followed by sand blasted samples (33.52 Mpa) and the least shear bond strength was shown by untreated samples (30.06 Mpa).

Conclusion: Chemically treated samples showed highest shear bond strength between acrylic denture teeth and denture base resin than laser irradiated, sand blasted and control samples.

Keywords: Injection molding, shear bond strength, laser surface treatment, chemical bonding agent, thermocycling, surface texture analysis

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I. Introduction

The most common reason for the elderly population to seek dental treatment is for the replacement of missing teeth by means of either complete or partial dental prosthesis. Although removable dental prosthesis is cannot be considered a substitute for natural teeth, they have remained the standard treatment of choice for geriatric edentulous patients.

Various materials and fabrication techniques have been employed for the construction of removable dental prosthesis. Acrylic resins, introduced in 1937, have enjoyed a continued popularity for the construction of removable prosthesis. It is still being considered as the major denture base material, mainly due its excellent esthetics, low water sorption and solubility, relative lack of toxicity, repair ability and simple processing technique.

Artificial teeth form an integral part of any removable prosthesis. Selection of denture teeth is mainly dependent on the clinical factors such as, the availability of inter ridge space, maxilla-mandibular relation, condition of supporting tissues and patients preference. Denture teeth are mostly available as either acrylic or porcelain. Polymethylmethacrylate employed in the construction of denture bases is used in the fabrication of artificial teeth and this similar chemical composition results in durable chemical bonding.

Durability of the denture is dependent on the strong adhesion between the denture teeth and the denture base resin. The interface between the denture teeth and the denture base resin remains the area of clinical concern. High incidence of de-bonding has been reported to occur at the tooth-denture interface which may be
attributed to several factors like; the direction of functional forces, the ridge lap surface area available for bonding, contamination of the denture teeth with wax or tin foil substitute, stage of packing of the denture base resin and length or cycle of polymerization.\textsuperscript{13,14,15,16,17}

With the predictable nature of osseointegrated dental implant, use of implant supported dentures are nowadays a common treatment option where acrylic teeth and PMMA denture base resin constitutes major part of the prosthesis. The forces generated due to the superior chewing efficiency provided by the implant prosthesis are sometimes detrimental to the bond resulting in tooth debonding\textsuperscript{6, 18, 19}.

Several methods have been advocated to enhance the bonding of acrylic resin teeth to denture bases. They can be broadly categorized into mechanical and chemical modifications or a combination of both.\textsuperscript{1,9,18,20,21,22}

Mechanical modification of ridge lap surface includes roughening without cutting or abrasive rotary instruments, placing diatorics and air abrading with aluminium oxide particles etc.\textsuperscript{1,7,18,23} All these mechanical methods produces varying degrees of roughness and irregularities on the acrylic tooth ridge lapsurface which increases the surface area, thereby increasing the bond strength between teeth and acrylic resin denture base.\textsuperscript{13,18,22,23}

A significant increase in bond strength has been reported in the literature by employing one of these methods for enhancing retention.\textsuperscript{11,13,20,24}

Sand blasting procedure involves spraying a stream of aluminium oxide particles against the material surface intended for bonding under highpressure.\textsuperscript{20} Air abrasion using aluminium oxide is one of the commonly followed micromechanical method of producing surface irregularities. Aluminium oxide of various particle sizes has been employed to enhance the bond between the acrylic teeth and denture base resin.\textsuperscript{1}

Progress in laser technology has shown a quick adoption for being used by many in the field of dentistry due to the development of the first working laser by Maiman in 1960. Recently, lasers have been found to provide relatively safe and easy means of altering the bonding surface of materials.\textsuperscript{1,27} Theoretically, it should benefit the bonding interface and result in stronger bond.\textsuperscript{1,18,20,25,26}

The results has shown that Er:YAG, Er,Cr:YSGG lasers were more effective than Nd:YAG and KTP lasers in increasing the bond between lining material and denture base resin due to their high energy potential.\textsuperscript{27,29} Akin et al\textsuperscript{27} had extrapolated the use of Er:YAG laser in the surface modification of acrylic teeth to denture base resin and has found an increase in bond strength. However, there are no studies reported in the literature using Er,Cr:YSGG laser as a method of surface modification.

Several chemicals were used to treat the bonding surface of acrylic tooth shortly before packing the resin in order to improve the bond. Chemicals such as non-polymerizable solvents, dissolved polymethyl methacrylate, monomer, tribochemical silica coating along with silanization, adhesives or combinations of the above has been documented in previous studies.\textsuperscript{1,7,18,22,23,30}

Chemical agents were used with the anticipation that it would enhance the monomer diffusion and result in the better polymer network formation. Studies have demonstrated that painting unmodified acrylic resin teeth with monomer, unfilled resin or bonding agent demonstrated higher bond strength between denture teeth and denture base resin.\textsuperscript{1,18,19,22}

Many studies have evaluated and compared the bonding of acrylic teeth to denture base resin by different polymerization methods like microwave activated, light activated, heat activated and chemically activated.\textsuperscript{1,6,30} These studies have revealed that heat-polymerizing method produced higher bond strength.\textsuperscript{6,7,8,11,12,13,31,32} Most of these studies had employed compression molding technique for the heat polymerization method.\textsuperscript{9,20,33,34,35} Although the compression moulding system had the advantages of ease of processing and lack of sophisticated equipments, it had disadvantages of dimensional inaccuracies resulting in improper fit of the denture base and also high processing stresses induced during resin polymerization.\textsuperscript{13,33}

Attempts to overcome the problems associated with compression molding technique have resulted in the development of the injection molding system by Pryor in 1942. Injection molding technique produces a more accurate denture compared to that produced by the compression-molding method.\textsuperscript{36,37,38} Other advantages over the compression molding technique include reduced processing time, lower skin sensitivity to the evaporated monomer and availability of the resin reservoir to compensate for acrylic resin shrinkage and less release of residual monomer.\textsuperscript{13,39} A study done by Lang et al\textsuperscript{32} and Vallitu et al\textsuperscript{18} have stated that injection pressing and high polymerization temperature of injection molding technique enhances the diffusion of monomer into the denture teeth, thus increasing bond strength between the acrylic resin teeth and the denture base.

Fluctuations in oral temperature brought about by intake of food and beverages leads to deterioration at the bonding interface and may constitute the reason for tooth de-bonding.\textsuperscript{2} The difference in coefficient of thermal expansion between the acrylic denture teeth and the denture base resin is considerable and this with the property of water sorption may play a vital role in sustaining the bond.\textsuperscript{48} Thermocycling procedures represent the
various temperature changes to which the prosthesis is subjected during use. The loss of bond strength due to thermocycling has been well documented 23,7,40

Surface treatments produce alterations in the surface texture of the substrate material. Changes in the surface topography may influence the surface area of the acrylic teeth which is available for both mechanical and chemical bonding. Surface texture analysis by 3-D surface profilometry aids in better visualization of the roughness on the treated surface and help to extrapolate the results with that of bond strength. 3-D surface profilometric analysis of surface treated acrylic teeth has not been documented in earlier studies.

In the literature numerous information regarding bonding mechanism and bond strength values of acrylic resin teeth to compression molded heat cure denture base resin is available.9,17,20,34,35,41 However research regarding the same with injection molding technique are few.22,23 Surface treatment with Er,Cr:YSGG laser is considered as an alternative to other surface treatment methods due to its depth of penetration based on material irradiated. Studies demonstrating Er,Cr:YSGG laser irradiation as the surface treatment modality of acrylic resin teeth are sparse.

There are several tests capable of evaluating the bond strength between acrylic teeth-acrylic denture base resin such as tensile, micro-tensile, peel and flexural.6,10,19 Many authors in the literature suggested the use of shear bond test as one of the most reliable method to evaluate the bond strength, since it concentrates the applied stress on the interface between two materials.1,4,13,35,41

In the light of the above considerations, the aim of the present in vitro study was to comparatively evaluate the shear bond strength between denture teeth and injection molded denture base resin with the effect of three different surface treatments on the ridge lap area namely sand blasting, application of chemical bonding agent and Er,Cr:YSGG laser irradiation, after the samples were subjected to thermocycling and to correlate the quantitative results with 3-D surface texture analysis.

II. Materials And Methods

The prototype wax model represents the rectangular wax specimen (3.5 x 1.5 x 1.5 cm³) with the denture tooth. The fabrication of this prototype model is necessary in order to prepare similar dimensions of test samples for the determination of shear bond strength. Maxillary dentulous cast is prepared from dentulous model former for the purpose of arrangement of denture tooth after the removal of corresponding tooth from the cast. Type-III dental stone (Kalstone, Kalabhai, Mumbai, India) was mixed as per manufacturer’s recommended water-powder ratio using clean rubber bowl and spatula (Classic, India) and poured into maxillary model former (Dental model former, Nissin & Co, Japan) and later allowed to set undisturbed. After the stone had completely set, the cast was retrieved from the model former.

Maxillary left central incisor tooth in the cast was trimmed completely till the cervical area and an acrylic maxillary left central incisor denture tooth (Cross-linked acrylic teeth, Aery pan XL, Ruthinium Dental Products, Italy) of mold size G2 and shade A1 was arranged on the trimmed portion of the cast. Labial inclination and incisal plane orientation of the acrylic denture tooth were adjusted using the glass dish with reference to the adjacent teeth present in the dentulous cast.

A putty index of the maxillary dentulous cast with the acrylic left central incisor denture tooth was made on a glass slab to facilitate the orientation of wax model later. Equal quantities of the base and catalyst of Polyvinylsiloxane putty impression material (Aquasil, Dentsply, Germany) were mixed and rolled into an U-shaped form. It was then placed on the glass slab to facilitate the placement of maxillary dentulous cast with left central incisor acrylic denture tooth. The putty material was adapted in such a way that it records the incisal third of the acrylic denture tooth. After the completion of polymerization, the maxillary cast and the index were separated and kept aside for later use in the orientation of wax model.

A sectional impression of the maxillary anterior region from the left canine to the right canine was obtained from the maxillary dentulous cast with left central incisor acrylic denture tooth, employing Polyvinylsiloxane putty and light body impression material (Aquasil, Dentsply, Germany) using a perforated plastic sectional impression tray (Prime dental product, Mumbai, India). The mixing and handling of the material were followed as per the manufacturer’s recommendation with the help of dispensing gun and auto mixing spiral.

The acrylic central incisor denture tooth arranged on the maxillary dentulous cast was removed and secured onto the corresponding region of the left central incisor in Polyvinylsiloxane impression. Molten modelling wax (Hindustan Modelling Wax, Hindustan Dental Products, Hyderabad, India) was gently flown into the impression and was allowed to solidify till it was completely hard. The wax model with the acrylic tooth was then retrieved from the Polyvinylsiloxane impression. The retrieved wax model was sectioned such that it contains the acrylic left central incisor denture tooth along with adjacent right central and left lateral wax teeth on either side. The sectioned wax model with acrylic tooth was then placed on the putty index insuch a manner that the acrylic tooth of the wax model was completely embedded in the indentation of the putty index.
A rectangular wax block of dimensions $2.5 \times 2 \times 2 \text{ cm}^3$ was fabricated. This wax block serves as the base for the sectioned wax model. The base will facilitate the attachment of the acrylized model to the testing jig of the universal testing machine.

The prepared wax block was placed on the platform of the dental surveyor (Para flex, Bego Germany) which was positioned parallel to the floor with the aid of spirit level indicator and was picked-up with surveying tool fixed to the surveying arm of the surveyor.

The glass slab with the putty index containing the sectioned wax model with the denture tooth was now placed on the platform of a surveyor. The surveyor arm along with the wax block was slowly lowered till it contacted the wax model and it was fused together. The wax model with the fused base was removed from the surveyor. The wax adjacent to the acrylic tooth was carved using wax carver (Lecrons wax carver, German dental instruments) to simulate the interdental portion as observed in the acrylic dental prosthesis. The wax base was adjusted in order to obtain a prototype wax model of $3.5 \times 1.5 \times 1.5 \text{ cm}^3$ dimensions. Thus one prototype wax model with denture tooth was prepared.

A plastic rectangular duplicator was used for the duplication of prototype wax model. The duplicator has two parts - a base and a container. The base had a circular opening for the provision for a funnel through which silicone duplicating material can be injected. The container was large enough to accommodate the prototype wax model so as to provide sufficient space for the duplicating material. The prototype wax model was fused to the base of the duplicator and the assembly was completed by securing the container over the base portion of the plastic duplicator. The base and the catalyst portion of the duplicating silicone material (KalSil Duplicating Silicone, Kalabhari, Mumbai, India) were mixed according to the manufacturer's instructions and poured over prototype wax model. After the set of the silicone material was verified, prototype model was retrieved from the duplicating silicone mold.

A slit opening was made on one of the walls of the mold to facilitate easy removal of wax specimens. The duplicated siliconemold of the prototype wax model will be used in preparing wax specimens of uniform dimension with the denture tooth. These wax specimens will be subjected to processing with injection molding acrylic resin.

Forty commercially available acrylic maxillary left central incisor denture teeth (cross-linked acrylic teeth, Aery pan XL, Ruthinium Dental Products, Italy) of similar size and shade (G2-Al) were selected, out of which ten acrylic denture teeth were used as control with no surfacetreatment. The remaining thirty acrylic denture teeth were subjected to surfacetreatment as follows:

The ridge lap area of the acrylic denture teeth ($n=10$) were subjected to sand blasting using $110\mu \text{m}$ aluminium oxide (Korox, Bego, Germany) The teeth were air abraded held at a distance of $10\text{ mm}$ from the nozzle, maintaining the pressure at $2\psi$ for a period of $30\text{ seconds}$ following which they were cleaned using a steam cleaner and the same procedure were followed for all the ten denture teeth. (Figure 1)

![Figure 1- Sandblasted denture tooth](image)
The ridge lap area of ten acrylic denture teeth (n=10) were coated with chemical bonding agent (Poly link IC, Bredent, senden, germany) as per manufacturer's instruction. It is a methylmethacrylate based adhesive agent used during the processing of acrylic dentures. Three covering coats of chemical bonding agent were applied to the ridge lap surface using an applicator with an application time of 30 seconds for each coat. The final coat of bonding agent was applied shortly before injection molding process and care was taken such that there was no contamination of the ridge lap area after application of bonding agent. The similar steps were done for all the ten denture teeth. (Figure 2)

Figure 2- Bonding agent treated denture teeth

The ridge lap area of ten acrylic denture teeth (n=10) were surface treated with an Er: YSGG laser system (WaterlaseiPlus laser unit, Biolase Technology, CA, USA). Laser irradiation was done on ridge lap area of acrylic denture teeth operating at the wavelength of 2.78μm, pulse duration of 700μs and repetition rate of 10 Hz. The power output was set at 3W according to test protocols. The air and water sprays from the handpiece were adjusted to a level of 85% air and 85% water to prevent the acrylic surface from overheating. Laser energy was delivered through a fiber optic system to a sapphire tip terminal 600μm in diameter and 6mm long. The focused laser beam was aligned to the ridge lap acrylic surface perpendicularly at the distance of 10mm. The area to be bonded was lased manually in a circular motion for a period of 30 seconds. (Figure 3)

Figure 3- Lase irradiated denture teeth

All the forty denture teeth were divided into four groups of ten teeth each according to the type of surface treatment rendered on the ridge lap area of those denture teeth. The denture teeth were divided into four groups as follows:
1. Group I (n=10) Untreated acrylic denture teeth. (Control group)
Comparative Evaluation of the Effect of Surface Treatments on The Shear Bond Strength between ..

2. Group-II (n=10) Sandblasted acrylic denture teeth (Sandblasted group)
3. Group-III (n=10) Chemical bonding treated acrylic denture teeth (Chemical bonding agent group)
4. Group-IV (n=10) Laser irradiated acrylic denture teeth (Laser irradiation Group)

No surface treatment was done for Group I to serve as a control. For Groups II and IV the surface treatments of the ridge lap area of the denture teeth were done prior to the de-waxing stage. For the Group III (Chemical bonding agent group) the surface treatment of the ridge lap area of the denture teeth was done after the de-waxing stage.

Four denture teeth comprising of one representative from each group were subjected to 3-D surface profile scanning. Surface roughness was measured using 3-D Non-contact Surface Profilometer (Taly surf CCI, Ametek, UK). The average surface roughness (Ra) value of each denture tooth was obtained. The magnification of the optical lens was 50x. Each denture tooth was placed under the objective lens and photomicrograph at 50x magnification to obtain 3-D and advanced 3-D views using Advanced Aspherics Analysis Software.

The selected acrylic maxillary left central incisor denture tooth of each group was positioned accurately in the indentation of the duplicated siliconemold individually. The molten wax was carefully flowed into the siliconemold. The wax was allowed to harden completely. After the wax had hardened, the wax specimen was retrieved from the silicone mold. Thus, forty such wax specimens were obtained for the four groups of denture teeth.

The wax specimens with the denture teeth were acrylized using injection molding technique using the SR Ivocap heat curing injection system (Ivoclar, Vivadent, Liechtenstein) in the following manner.

A special two compartment thermal insulating flasks was used for the injection molding system. Model plaster (Kaldent, Kalabhai, Mumbai, India) were mixed according to the manufacturer's recommendations and were filled into lower compartment of the flask. Wax specimens were positioned in the flask such that the base of the wax specimen was embedded in the model plaster. All the wax specimens were connected to one another using wax channel and were finally sealed to main channel. This was done to ensure continuity in the flow of the resin. A separating fluid (Ivoclar, Vivadent, Liechtenstein) was applied onto the plaster surface as per the manufacturer's recommendation and flashing procedure were completed with the counter pour. After de-waxing, bonding surfaces of the teeth were scrubbed with detergent, rinsed with clean boiling water and visually inspected to ensure complete elimination of wax.

For group III test teeth, after de-waxing, chemical bonding agent (Poly.link IC, Bredent, Senden, Germany) was applied over the ridge lap surface of the acrylic teeth according to the manufacturer's instruction. Three covering coats of bonding agent were applied to the ridge lap surface using bonding agent applicator with the application time of 30 seconds for each coat as per the manufacturer's instruction. The final coat was applied shortly before the injection process.

For acrylization, a standard capsule containing 20 gm polymer and 30 ml monomer of SR Ivocap Plus (Ivoclar Vivadent Inc, Liechtenstein, Germany) (Fig. 4) was used. The monomer was poured into the capsule and triturated in the cap vibrator for 5 minutes. Then, the flask was closed and placed under 3 tons of pressure in a clamping frame, in a hydraulic press. The material was injected into the mold under 6 bar of pressure for 5 minutes with the manufacturer's pressure apparatus. Then the SR Ivocap assembly was placed in the polymerization bath. The temperature of the water bath was set at 100°C in such away that the water boiled during the entire period. The polymerization period (begins with the boiling of water) was 35 minutes. After the polymerization period, SR Ivocap assembly was removed from the boiling water and immediately placed in cold water.

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After 20 minutes the pressure apparatus was removed but clamping frame together with flask remained in cold water for an additional 10 minutes. Following de-flasking, the test samples were retrieved and flash was trimmed using acrylic trimmer (Fig 26). Sandpapers of coarse and fine grit (Fig 11) were used to smoothen the samples. A total of forty samples were prepared in the similar manner.

In the present study thermocycling was done to simulate the intra oral conditions. All the samples of Group I, II, III and IV were subjected to thermocycling for 1000 cycles in a distilled water bath between 5° C and 55° C with the dwell time of 20 seconds and a dry time of 10 seconds using a thermocycling apparatus (HaakeWillytec, Germany) (Fig. 27). Upon completion of thermocycling the samples were stored in distilled water (Merck, Mumbai, India) (Fig. 12) in their respective container at room temperature, until they were subjected to shear bond strength testing.

A total of forty test samples (Group I, II, III and IV) were tested for shear bond strength in a universal mechanical testing machine (Lloyd’s universal testing machine, U.K.) (Fig. 28) at the Department of Polymer Technology, Central Institute of Plastic Engineering Technology Guindy, Chennai, India. (Figure 5)
A 2mm groove was placed with a straight fissure bur on the palatal aspect of the denture teeth at the bonding interface between the acrylic teeth and acrylic resin block so as to facilitate proper seating of the testing chisel and to prevent it from slippage during application of the load. Test samples were fixed to the sample fixture at the bench vice of the machine with the mono beveled chisel blade placed flat against the 2 mm groove on the palatal aspect of denture teeth.

Force was applied to the samples so that shear load was exerted at the bonding interface at a crosshead speed of 1mm/min until the fracture occurred. Load deflection curves and ultimate load to failure were recorded and displayed by the computer software of the testing machine. Shear bond force was recorded in newton (N) and shear bond strength (MPa) was calculated through dividing the load (N) at which failure occurred by the bonding area (mm$^2$).

\[
\text{Bond strength (MPa) = load (N) + surface area (mm}^2\text{)}
\]

The results were tabulated and subjected to statistical analysis. The SPSS (SPSS 16 for Windows 8.0, SPSS Software Corp., Munich, Germany) software package was used for statistical analysis. Mean and standard deviation were estimated from the results obtained from each sample for each study group. The data were analysed with One Way Analysis Of Variance (ANOVA) and pair-wise comparison of mean values was done by post-hoc test (Tukey’s HSD analysis). Statistical significance was considered at 5% significance level. After shear bond strength testing, the mode of bond failure was determined for every test sample by visual examination by a single operator and was categorized into one of three categories as adhesive, cohesive and mixed failure.

### III. Results

#### Table 1: Basic values of shear bond strength between untreated denture teeth and denture base resin (Group I)

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Shear bond strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28.1</td>
</tr>
<tr>
<td>2</td>
<td>33.3</td>
</tr>
<tr>
<td>3</td>
<td>24.9</td>
</tr>
<tr>
<td>4</td>
<td>29.4</td>
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<tr>
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<td>30.5</td>
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<td>28.5</td>
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<td>7</td>
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<td>8</td>
<td>27.9</td>
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<td>9</td>
<td>34.1</td>
</tr>
<tr>
<td>10</td>
<td>31.8</td>
</tr>
<tr>
<td>MEAN/SD</td>
<td>30.06/2.83</td>
</tr>
</tbody>
</table>
**Inference:**
The maximum shear bond strength is 34.1 MPa
The minimum shear bond strength is 24.9 MPa
The mean shear bond strength is 30.06 MPa

**Table 2:** Basic values of shear bond strength between sandblasted denture teeth and denture base resin (Group II)

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Shear bond strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
<td>2</td>
<td>36.9</td>
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<tr>
<td>3</td>
<td>33.4</td>
</tr>
<tr>
<td>4</td>
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<td>34.7</td>
</tr>
<tr>
<td>10</td>
<td>27.5</td>
</tr>
<tr>
<td><strong>MEAN/SD</strong></td>
<td><strong>33.52/3.77</strong></td>
</tr>
</tbody>
</table>

**Inference:**
The maximum shear bond strength is 38.7 MPa
The minimum shear bond strength is 27.5 MPa
The mean shear bond strength is 33.52 MPa

**Table 3:** Basic values of shear bond strength between chemical bonding agent treated denture teeth and denture base resin (Group III)

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Shear bond strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<tr>
<td>2</td>
<td>44.4</td>
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<td>3</td>
<td>36.5</td>
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<tr>
<td>10</td>
<td>42.4</td>
</tr>
<tr>
<td><strong>MEAN/SD</strong></td>
<td><strong>42.44/4.56</strong></td>
</tr>
</tbody>
</table>

**Inference:**
The maximum shear bond strength is 48.1 MPa
The minimum shear bond strength is 36.2 MPa
The mean shear bond strength is 42.44 MPa

**Table 4:** Basic values of shear bond strength between laser irradiated denture teeth and denture base resin (Group IV)

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Shear bond strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>2</td>
<td>35.7</td>
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<tr>
<td>3</td>
<td>30.5</td>
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<tr>
<td>4</td>
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<tr>
<td>10</td>
<td>32.7</td>
</tr>
<tr>
<td><strong>MEAN/SD</strong></td>
<td><strong>35.71/4.12</strong></td>
</tr>
</tbody>
</table>

**Inference:**
The maximum shear bond strength is 42.3 MPa
The minimum shear bond strength is 29.8 MPa
The mean shear bond strength is 35.71 MPa
Table 5: Comparative evaluation of the mean shear bond strength of untreated samples (Group I), sandblasted samples (Group II), chemical bonding agent treated samples (Group III) and laser irradiated samples (Group IV) :ANOVA

<table>
<thead>
<tr>
<th>Groups</th>
<th>Mean shear bond strength (MPa)</th>
<th>Standard deviation</th>
<th>'p' value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>30.06</td>
<td>2.83</td>
<td>0.001*</td>
</tr>
<tr>
<td>Group II</td>
<td>33.52</td>
<td>3.77</td>
<td></td>
</tr>
<tr>
<td>Group III</td>
<td>42.44</td>
<td>4.56</td>
<td></td>
</tr>
<tr>
<td>Group IV</td>
<td>35.71</td>
<td>4.12</td>
<td></td>
</tr>
</tbody>
</table>

*p<0.05, statistically significant

Inference: One Way Analysis Of Variance (ANOVA) shows statistically significant difference between the test groups at 5% level. Group III showed the highest mean shear bond strength followed by Group IV, followed by Group II and the least by Group I

Table 6: Multiple comparisons of mean shear bond strength of Group I, Group II, Group III and Group IV denture teeth to denture base resin (Post-hoc Tukey HSD analysis)

<table>
<thead>
<tr>
<th>Groups</th>
<th>Mean shear bond strength (MPa)</th>
<th>'p' value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>30.06</td>
<td>0.209</td>
</tr>
<tr>
<td>Group II</td>
<td>33.52</td>
<td></td>
</tr>
<tr>
<td>Group I</td>
<td>30.06</td>
<td>0.001*</td>
</tr>
<tr>
<td>Group III</td>
<td>42.44</td>
<td>0.013*</td>
</tr>
<tr>
<td>Group I</td>
<td>30.06</td>
<td></td>
</tr>
<tr>
<td>Group IV</td>
<td>35.71</td>
<td>0.001*</td>
</tr>
<tr>
<td>Group II</td>
<td>33.52</td>
<td>0.592</td>
</tr>
<tr>
<td>Group III</td>
<td>42.44</td>
<td></td>
</tr>
<tr>
<td>Group II</td>
<td>33.52</td>
<td>0.592</td>
</tr>
<tr>
<td>Group IV</td>
<td>35.71</td>
<td></td>
</tr>
<tr>
<td>Group III</td>
<td>42.44</td>
<td>0.001*</td>
</tr>
</tbody>
</table>

p* < 0.05, statistically significant

Inference
Gr II was higher than Gr I with no statistical significance (p>0.05)
Gr III was significantly higher than Gr I (p <0.05)
Gr IV was significantly higher than Gr I (p <0.05)
Gr III was significantly higher than Gr II (p <0.05)
Gr IV was higher than Gr II with no statistical significance (p>0.05)
Gr III was significantly higher than Gr IV (p<0.05)

IV. Discussion
The long term success of removable dental prosthesis depends not only on the expertise of the operator, but also on nature and properties of dental materials involved in denture fabrication. The three most important requisites for a predictable functioning of the removable dental prosthesis mainly the teeth bearing portion are hardness/wear resistance, durable bond strength to the denture base resin and color stability. The bond strength of artificial teeth is paramount for the longevity of removable prosthesis especially in situations when maxillary complete denture opposes natural dentition, fixed dental prostheses and implant supported restoration.

It has been estimated that between 22% - 30% of denture repairs involve tooth de-bonding, usually in the anterior region of the denture. This detachment may be attributed to a lesser ridge lap surface area available for bonding in the anterior region, mechanical fatigue and the direction of the stresses from repeated chewing and accidental falling. The major parameters affecting the bond strength are acrylic tooth material, surface modification of ridge lap area and composition of denture base resin.

The mode of attaining a bond between the acrylic teeth and the denture base resin involves, the polymerizing denture base resin must come in physical contact with the denture tooth resin and the polymer network of denture base resin must react with acrylic tooth polymer to form an interpenetrating polymer network (IPN). De-bonding may be the result of incompatibilities at the tooth and base interface.

Majority of the manufacturers produce teeth and denture base resin with little or no mention of the bond strength or compatibility between teeth and base materials which could have an influence on the durability and repair potential.
Several methods have been employed to enhance the bonding of acrylic resin teeth to denture base which can be either mechanical or chemical modification of ridge lap portion or a combination of both. Mechanical methods can be further categorized into macromechanical and micromechanical. Macromechanical means of altering the tooth bondingsurface includes grinding the glazed surface, placements of vertical and horizontal grooves and diatorics. Micromechanical surface alterations include high energy air abrasion with 50μm, 100μm or 250μm aluminium oxide. In removable prosthodontics air abrasion with Al2O3 is the conventional surface treatment procedure done on the intaglio surface of dentures before relining procedures to enhance mechanical bonding. Various studies have reported that airborne particle abrasion increases the surface area of the ridge lap portion of the denture teeth and hence improves their bond strength to denture base resin.

Chemical method of surface conditioning the bond surface employs the application of monomer, non polymerizable solvents such as dichloro methane, acetone and chloroform. The application of chemical bonding agent is commonly preceded by a slight mechanical surfacemodification as recommended by manufacturer. Most of the chemical solvents facilitate the swelling of denture tooth polymer and thereby enhancing the diffusion of polymerizable materials, mainly MMA, from the denture base resin. This improves the extent and quality of the inter-penetrating network at the completion of polymerization.

The use of lasers in dentistry has widened its application as a means of altering the surface characteristics of the material’s bonding interface. In removable prosthodontics surface irradiation using laser is considered as one of the mechanical method of surface modification at the bonding interface of restorative material. Similar in fixed prosthodontics surface lasing on the metal substructure has been advocated before porcelain addition in order to augment metal-ceramic bond. In implant prosthodontics laser surfacetreatment is utilized as one of the surface modification method to enhance contact between bone and implant thread surface. Studies demonstrating the use of laser irradiation as a surface treatment modality on the ridge lap portion of acrylic tooth bonded to PMMA denture base resin are sparse. 

Type of denture teeth used can also affect the integrity of the bond when processed to acrylic resins. Denture teeth are primarily composed of polymethylmethacrylate and have been increasingly modified to improve their physical property by incorporating cross-linking agents, using different monomers and addition of fillers. Cross-linking agents are generally used to improve properties such as flexural strength, hardness, wear resistance, crazing resistance which help increase prosthesis longevity. Bond strength of artificial tooth resin to denture base resin has been related to the ability of monomer to diffuse into the tooth resin. This is significantly affected by cross linked teeth due to its highly condensed matrix, hampering the diffusion of monomer into the matrix. Therefore ridge lap portion of the acrylic teeth is expected to be less cross linked so as to facilitate bonding into the denture base resin.

The method of processing of acrylic dentures could also influence the bond between the teeth and resin denture base. Compared to the conventional compression molding technique, injection molding does not have any heat conduction, leading to the rise in polymerization temperature thereby resulting in increased rate of monomer diffusion from the denture base polymer mixture into the acrylic teeth polymer which is a prerequisite for the formation of interpenetrating polymer network (IPN). Moreover injection molded denture base acrylic system results in negligible change in dimensions and vertical dimension of occlusion.

In vitro studies have been done to evaluate the bond between acrylic denture teeth and acrylic denture base resin subjected to conventional surfacetreatments like air abrasion, placement of grooves, application of chemical bonding agents etc. However studies reporting on the efficacy of laser surface irradiation on shear bond strength are lacking, also there is a paucity of studies comparing the bond strength of acrylic teeth-denture basefabricated by injection molded technique.

According to ISO 3336, the optimal shear bond strength value of acrylic teeth bonded to denture base resin is 31 MPa. In the present study the shear bond strength values of all the test groups exhibited higher value than the recommended. Chemical bonding agent treated samples (42.44 MPa) showed significantly higher bond strength compared to control (30.06 MPa), sandblasted samples (33.52 MPa) and laser irradiated samples (35.71 MPa)(p < 0.05).

The highest shear bond strength value produced by chemical bonding agent surface treatment for Group III could be explained on the basis that methylmethacrylate based bonding agent applied to the ridge lap portion before acrlyisation provided a solvent effect on the tooth surface, thereby increasing the wettability and favouring a more effective diffusion of the monomer present in the denture base polymer across the tooth denture base interface and resulting in the formation of a durable interpenetrating polymer network. Another factor that could have an effect on the bonding interface is the method of processing, injection molding technique results in an increase in polymerization temperature which is conducive for higher diffusion of monomer from the denture base polymer resulting in higher bond strength.

In the present study, a chemical bonding agent Poly.link I.C was used. It is an adhesive agent for acrylic teeth and contains methyl methacrylate as the main ingredient. Three covering coats of bonding agent were
applied, with the application time of 30 seconds for each coat. Rached et al. \(^\text{19}\) and Sarac et al. \(^\text{47}\) have stated that an application time of 30 seconds was found to be effective in increasing the bond strength. Hence, an application time of 30 seconds was used in the present study. In addition, Vallitu et al. \(^\text{32}\) had also stated that the time lapse between the application of chemical solvent and packing could influence the bond strength. Longer time lapse results in evaporation of the chemical solvent from the ridge lap area, allowing litesolvent interaction with the monomer from the denture base resin. Shorter time interval will produce better bond formation. Therefore the final coat of bonding agent was applied shortly before the injection process in this study.

The probable reason for the highest bond strength in chemical bonding agent is that the application of chemical bonding agent dissolves part of PMMA of the tooth and provides free double bonds, that may co-polymerisewith the PMMA of the denture base resin, forming a durable interpenetrating polymer network (IPN) structure, improving the bond between the tooth and acrylic resin. \(^\text{22,27,49}\) The results obtained in the present study were similar to the results of Saavedra et al. \(^\text{8}\) (38.0 MPa), Lang et al. \(^\text{42}\) (36 MPa) and Fletcher et al. \(^\text{48}\).

Various other chemicals were employed in the previous studies. \(^\text{7,22,23}\) Takahashi et al. \(^\text{25}\) reported the application of dichloromethane as a chemical bonding agent and achieved a significant improvement in bond strength of acrylic denture teeth to denture base resin.

Laser irradiated samples exhibited significantly higher bond strength (35.71 MPa) than the control samples (30.06 MPa) but significantly lesser when compared to chemical bonding agent treated samples (42.44 MPa) (\( p' < 0.05 \)). The bond strength was higher than sand blasted samples without any statistical significance (33.52 MPa) (\( p' > 0.05 \)).

Laser application may cause some chemical changes on the acrylic surface because of thermal degradation. This can be explained by the high energy produced by Er, Cr: YSGG laser. The energy produced by this laser is due to the interaction with the water droplet at the bonding surface in order to create the water molecule excitation resulting in micro-expansion and propulsion. An increased surface area may be formed by this expansion which causes the surrounding material to ablate. \(^\text{25}\) These events are believed to be responsible for the increase in the bond strength values when compared to sandblasting and untreated (control) group.

Akin et al. \(^\text{27}\) reported that altering the PMMA surface by Er: Y AG laser significantly improve the bond strength in PMMA/silicone specimens and also demonstrated that other laser systems like Nd: YAG and KTP laser are ineffective in strengthening the bond. He also reported that Er: YAG laser treatment at 10 Hz, 3W and 300 mJ with long pulse duration was shown to be effective method of improving the bond strength of UDMA and liners. The present study followed the same parameters used for Er: Y AG laser as adapted by Akin et al. \(^\text{27}\).

The shear bond strength of sandblasted samples (33.52 MPa) was higher than control samples (30.06 MPa) and lesser than laser irradiated samples (35.71 MPa) but does not have statistical significance (\( p' > 0.05 \)). The shear bond strength was significantly lower than chemical bonding agent treated samples (42.44 MPa) (\( p' < 0.05 \)). Air abrasion using alumina particles on the ridge lap portion of the acrylic teeth increased the surface energy and surface roughness, thereby it was the monomer from the denture base polymer matrix. \(^\text{20}\)

Sandblasting with different grits of aluminium oxide has been employed in the literature. A study done by Barpal et al. \(^\text{20}\) revealed that sandblasting the ridge lap area with 50 μm could only remove the glaze on the ridge lap area but had no significant effect in improving the bond strength between the denture base resin and acrylic resin teeth. Most of the studies reported that grit size in the range of 120 μm Al₂O₃ particle is adequate to improve the bond strength. \(^\text{1,22,27}\)

Hence in the present study, Aluminium oxide of 110 μm was chosen and sandblasting was done at the distance of 10 mm from the nozzle, maintaining the pressure at 2 psi for a period of 30 seconds. The lower bond strength value revealed by the sandblasted group could be explained on the basis that the depth of penetration by the alumina particles were found to be shallow when compared to laser etching thus producing lesser surface irregularities.

The values obtained in the present study for sand blasting group were similar to the results of Geerst et al. \(^\text{32}\) (32 MPa) and Nishigawa et al. \(^\text{22}\). Various studies have reported that bond between denture teeth and denture base also depends on the processing technique and type of resin employed. \(^\text{13,18,38,44}\) In the present study heat curing injection molding technique was employed for acrylization using SR Ivocap high impact resin.

Vallitu et al. \(^\text{12}\) in his study concluded that heat curing is the best procedure to obtain good bonding between acrylic denture teeth and polymethylmethacrylate denture base polymer. He stated that increased polymerization temperature that enhances the more diffusion of monomer is the contributing factor. Numerous studies have shown that injection molding technique has advantage of less polymerization shrinkage thereby producing accurate denture. \(^\text{36,37,39,45,52}\) Furthermore, the pressure used to inject the acrylic dough might enhance the diffusion of monomer from the denture base acrylic resin into the acrylic resin polymer of the tooth.
Comparative Evaluation of the Effect of Surface Treatments on The Shear Bond Strength between... 

Cunningham et al. demonstrated that high-impact heat cured resin shown to have better bond to cross linked teeth than a conventional heat cure resin. Similar result was shown by Fletcher et al., Huggett et al. and Morrow et al. The effect of the thermocycling on the bond strength was also evaluated in the present study. Thermocycling is used to closely simulate the oral condition and to assess the durability of bond. All the test samples were subjected to thermocycling for 1000 cycles between 5° C and 55° C with the dwell time of 20 seconds. Various studies have reported that thermocycling decreased the bond strength between denture teeth and acrylic resin of all polymerization methods. Amin et al. in a study demonstrated that deterioration of the bond strength was attributed to leaching of monomer and water sorption resulting in some interfacial separation.

In the present study, the 3-D surface texture analysis of one representative denture tooth sample from each test group was evaluated using 3-D Surface Profilometer. The highest average surface roughness value was exhibited by denture tooth sample surface treated by laser irradiation (Group IV) (Ra - 1.70μm) followed by denture tooth sample surface treated by Sand blasting (Group II) (Ra - 1.58μm) followed by denture tooth sample surface treated by chemical bonding agent (Group III) (Ra - 0.62μm). The least average roughness value was exhibited by untreated denture tooth sample (Group I) (Ra - 0.44μm).

Group IV (Ra) > Group II (Ra) > Group III (Ra) > Group I (Ra)

The increase in amount of surface roughness obtained for laser Indicated denture tooth could be based on the fact that the depth of penetration by the laser energy yields increased area of rough surface as evidenced by well-defined peaks and valleys when examined under advanced 3-D imaging. The surface topography of sandblasted denture tooth is due to the high energy abrasive action of alumina particles resulting in better penetration of the substrate surface.

The Ra value obtained with the denture tooth treated with chemical bonding agent demonstrated the presence of rougher surface than the untreated denture tooth sample. The roughness obtained is due to the dissolving action of the solvent on the superficial portion of the ridge lap. However, this Ra value was lesser when compared to that observed with sandblasting and laser surface treatment. (Figure 6, 7, 8, 9)

Figure 6- 3D surface texture analysis of untreated denture tooth of Group I
Figure 7- 3D surface texture analysis of sandblasted denture tooth of Group 11

Figure 8-3D surface texture analysis of chemical bonding agent treated denture tooth of Group 11
The type of failure also needs to be considered because fracture may occur in the denture tooth before occurring at the interface between tooth and denture base. Bond failures could be adhesive, cohesive or mixed failure. In the present study, most of the failures that occurred were mixed type of failure.

Group I samples exhibited predominantly adhesive failure. In Group II, a majority of samples exhibited adhesive failure and remaining samples exhibited mixed failures with predominant adhesive patterns. The mode of failure observed in Group I and Group II samples are suggestive of weaker bond strength as Group I samples were not rendered any surface treatment and sandblasting created only shallow surface irregularities in Group II. Group III and Group IV samples exhibited predominantly cohesive failures followed by mixed failures with predominant cohesive patterns. This indicates better penetration of MMA into acrylic tooth polymer forming a durable interpenetrating polymer network and higher roughness caused by laser irradiation ensuring better bond in Group IV, which reflected in their high values of shear bond strength.

On overall appraisal of the results obtained from the present study, untreated samples (Group I) exhibited least shear bond strength among the groups tested. This is in correlation with the least Ra value obtained and the adhesive failure observed, which indicates a weaker bond.

Sandblasted samples (Group II) demonstrated a marginal improvement in shear bond strength over Group I, but lesser when compared to Group III and Group IV. This moderate increase is attributed to the higher Ra value as compared to Group I. The slightly lower shear bond strength value observed for Group II as compared to Group IV could be attributed to the better surface roughness obtained by laser surface treatment (Group IV) and also the predominantly cohesive mode of failure observed in the group II samples.

Group III produced the highest shear bond strength value among all the tested groups. The cohesive and mixed mode of failure were seen in these samples. Although the surface roughness value of the chemically treated denture tooth was lesser than the sandblasted and laser treated denture tooth, the significantly higher shear bond strength values obtained could be attributed to the chemical action of the bonding agent.

Laser surface treated samples Group IV revealed higher shear bond strength value than Group I and Group II but lesser than Group III. The results derived from the shear bond testing for Group IV are in concurrence with the observations from surface profilometry and also the cohesive and mixed type of failures observed on visual examination. Within the limitations of this present study, on overall comparison, denture teeth samples treated with chemical bonding agent exhibited higher shear bond strength value, followed by laser surface treated samples as compared to those obtained by air abrasion procedures.

The present study had some limitations. The samples were rested after subjecting them to thermocycling only. Hence situations replicating clinical scenarios and cyclic loading should be included in future studies. As far as the laser surface treatment, different energy levels should be employed in order to vary.
depth of penetration in the subsequent studies. The effect of surface treatments on denture base materials such as UDMA. Nylon based polyamide materials should be investigated in future studies.

V. Conclusions

Surface modification on the ridge lap area of area of acrylic denture teeth by application of chemical bonding agent yielded highest shear bond strength. The surface treatments by both sandblasting and laser surface etching had also exhibited adequate bond strength. Surface treatments by all the above methods had resulted in shear bond strength values greater than the requirement of ISO 3336. Hence all the surface treatments carried out in this study can be used to improve the bond strength between acrylic denture teeth and injection molded PMMA.

References

Comparative Evaluation of the Effect of Surface Treatments on The Shear Bond Strength between Acrylic Resin Denture Teeth and Denture Base Resin – Three Dimensional Study


Prof Dr. Hariharan Ramakrishnan. “Comparative Evaluation of the Effect of Surface Treatments on The Shear Bond Strength between Acrylic Denture Teeth and Denture Base Resin – Three Dimensional Study.” IOSR Journal of Dental and Medical Sciences (IOSR-JDMS), vol. 18, no. 12, 2019, pp 29-45.