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Comparative Evaluation of the Effect of Surface Treatments on Theshearbond 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 cornparatively 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, II 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: synthetic resins, shear strength, lasers, dental bonding, artificial tooth, acrylic resins

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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 completeor partial dental prosthesis. Although removable dental prosthesis is cannot beconsidered a substitute for natural teeth, they have remained the standardtreatment of choice for geriatric edentulous patients.

Various materials and fabrication techniques have been employed forthe construction of removable dental prosthesis.[1,2] Acrylic resins, introducedin 1937, have enjoyed a continued popularity for the construction ofremovable prosthesis.[3]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.[4]

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 ofthe supporting tissues and patientspreference. Denture teeth are mostlyavailable as either acrylic or porcelain.[5]Polymethylmethacrylate employed inthe construction of denture bases is used in the fabrication of artificial teethand this similar chemical composition results in durable chemicalbonding.[6,7,8,9,10,11,12,]

Durability of the denture is dependent on the strong adhesion betweenthe denture teeth and the denture base resin. The interface between the dentureteeth and the denture base resin remains the area of clinical concern. Higherincidence of. de-bonding has been reported to occur at the tooth-dentureinterface which may be attributed to several factors like; the direction offunctional forces ,the ridge lap surface area available for bonding,contamination of the denture teeth with wax or tin foil substitute, stageof packing of the denture base resin and length or cycle ofpolymerization.[13,14,15,16,17]

With the predictable nature of osseointegrated dental implant, use ofimplant supported dentures are nowadays a common treatment option whereacrylic teeth and PMMA denture base resin constitutes major part of theprosthesis. The forces generated due to the superior chewing efficiencyprovided by the implant prosthesis are sometimes detrimental to the bondresulting intooth de-bonding.[8,],[18,,19]

Several methods have been advocated to enhance the bonding ofacrylic resin teeth to denture bases. They can be broadly categorized intomechanical and chemical modifications or a combination of both .[1,9,1920,21,22]

Mechanical modification of ridge lap surface includes roughening withcutting or abrasive rotary instruments, placing diatorics and air abrading withaluminium oxide particles etc.[1,7,18,23] All these mechanical methods producesvarying degrees of roughness and irregularities on the acrylic tooth ridge lapsurface which increases the surface area, thereby increasing the bond strengthbetween teeth and acrylic resin denture base.[13,18,22,23]

A significant increase in bond strength has been reported in the literature by employing one of thesemethods for enhancing retention.[11,13,20,24,]

Sand blasting procedure involves spraying a stream of aluminiumoxide particles against the material surface intended for bonding under highpressure.[20] Air abrasion using aluminium oxide is one of the commonlyfollowedmicromechanical method of producing surface irregularities.Aluminium oxide of various particle sizes has been employed to enhance thebond between the acrylic teeth and denture base resin.[1,18,20,25,26]

Progress in laser technology has shown a quick adoption for beingused by many in the field of dentistry due to the development of the firstworking laser by Maiman in 1960. Recently, lasers have been found to providerelatively safe and easy means of altering the bonding surface ofmaterials. [1],[27,28,29] Theoretically, it should benefit the bonding interface and result in stronger bond. [1,27,] Laser irradiation with various lasers like Er:YAG,Er,Cr:YSGG, Nd:YAG, KTP lasers have been used in few studies to modifythe intaglio surface of the denture before application of liner materials.[1,27,29]

The results has shown that Er:YAG, Er,Cr:YSGG lasers were more effectivethan Nd:YAG and KTP lasers in increasing the bond between lining materialand denture base resin due to their high energy potential .[27,29] Akin et al[27] hadextrapolated the use of Er:YAG laser in the surface modification of acrylicteeth to denture base resin and has found an increase in bond strength.However, there are no studies reported in the literature using Er,Cr:YSGGlaser as a method of surface modification..

Several chemicals were used to treat the bonding surface of acrylictooth shortly before packing the resin in order to improve the bond. Chemicalsuch as non-polymerizable solvents, dissolved polymethyl methacrylate,monomer, tribochemical silica coating along with silanization, adhesives orcombinations of the above has been documented in previousstudies.[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 withmonomer, unfilled resin or bonding agent demonstrated higher bond strengthbetween denture teeth and denture base resin.[1,18,19,22]

Many studies have evaluated and compared the bonding of acrylicteeth to denture base resin by different polymerization methods likemicrowave activated, light activated, heat activated and chemicallyactivated. [1,6,30] These studies have revealed that heat-polymerizing methodproduced higher bond strength. [6,7,9,11,12,13,31,32] Most of these studies hademployed compression molding technique for the heat polymerizationmethod.[9,20,33,34,35]Although the compression moulding system had theadvantages of ease of processing and lack of sophisticated equipments, it haddisadvantages of dimensional inaccuracies resulting in improper fit of thedenture base and also high processing stresses induced during resinpolymerization.[13,33]

Attempts to overcome the problems associated with compressionmolding technique have resulted in the development of the injection moldingsystem by Pryor in 1942. Injection molding technique produces a moreaccurate denture compared to that produced by the compression-moldingmethod. [36,37,38] Other advantages over the compression molding techniqueincludes reduced processing time, lower skin sensitivity to the evaporatedmonomer and availability of the resin reservoir to compensate for acrylicresin shrinkage and less release of residual monomer. [13,39] A study done byLang et al [42] , Vallitu et al[52]and have stated that injection pressing and highpolymerization temperature of injection moldingtechnique enhances thediffusion of monomer into the denture teeth, thus increasing bond strengthbetween the acrylic resin teeth and the denture base.

Fluctuations in oral temperature brought about by intake of food andbeverages leads to deterioration at the bonding interface and may constitutethe reason for tooth de-bonding.[2]The difference in coefficient of thermalexpansion between the acrylic denture teeth and the denture base resin isconsiderable and this with the property of water sorption may play a vital rolein sustaining the bond.[40]Thermocyclingprocedures represent the varioustemperature changes to which the prosthesis is subjected during use. The lossof bond strength due thermocycling has been well documented .[2,3,7,40]

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

In the literature numerous information regarding bonding mechanism and bond strength values of acrylic resin teeth to compression molded heatcure 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:YSGGlaser irradiation as the surface treatment modalityof acrylic resin teeth is sparse.

There are several test capable of evaluating the bond strength betweenacrylic teeth-acrylic denture base resin such as tensile, micro-tensile, peel andflexural. [6,10.19]Many authors in the literature suggested the use of shear bondtest as one of the most reliable method to evaluate the bond strength, since itconcentrates 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 vitrostudy was to comparatively evaluate the shear bond strength between dentureteeth and injection molded denture base resin with the effect of three differentsurface treatments on the ridge lap area namely sand blasting, application ofchemical bonding agent and Er,Cr:YSGG laser irradiation, after the sampleswere subjected to themocycling and to correlate the quantitative results with3-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 cm^3) with the denture tooth. The fabrication of this prototypemodel is necessary in order to prepare similar dimensions of test samples forthe determination of shear bond strength.Maxillary dentulous cast is prepared from dentulous model formerfor the purpose of arrangement of denture tooth after the removal ofcorresponding tooth from the cast. Type-III dental stone (Kalstone, Kalabhai,Mumbai, India) was mixed as per manufacturer'srecommendedwater-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 thestone hadcompletely set, the cast was retrieved from the model former.

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

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

A sectional impression of the maxillary anterior region from the leftcanine to the right canine was obtained from the maxillary dentulous cast withleft central incisor acrylic denture tooth, employing Polyvinylsiloxane puttyand 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 werefollowed as per the manufacturer's recommendation with the help ofdispensing gun and auto mixing spiral.

The acrylic central incisor denture tooth arranged on the maxillarydentulous cast was removed and secured onto the corresponding region of leftcentral incisor in Polyvinylsiloxane impression. Molten modelling wax(Hindustan Modelling Wax, Hindustan Dental Products, Hyderbad, India) was gently flown into the impression and was allowed to solidify till itwas completely hard. The wax model with the acrylic tooth was then retrievedfrom the Polyvinylsiloxane impression. The retrieved wax model wassectioned such that it contains acrylic left central incisor denture tooth alongwith adjacent right central and left lateral wax teeth on either side. Thesectioned wax model with acrylic tooth was then placed on the putty index insuch a manner that the acrylic tooth of the wax model was completelyembedded in the indentation of the putty index.

A rectangular wax block of dimensions 2.5 x 2 x 2 cm^3 was fabricated. This wax block serves as the base for the sectioned wax model. The base willfacilitate the attachment of the acrylized model to the testing jig of theuniversal testing machine.

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

The glass slab with the putty index containing the sectioned wax modelwith the denture tooth was now placed on the platform of a surveyor. Thesurveyor 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 wasremoved from the surveyor. The wax adjacent to the acrylic tooth was carvedusing 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 of3.5 x 1.5 x 1.5 cm^3 dimensions. Thus one prototype wax model with denture tooth was prepared.

A plastic rectangular duplicator was used for the duplicationof 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 whichsilicone duplicating material can be injected. The container was large enoughto accommodate the prototype wax model so as to provide sufficient space forthe duplicating material. The prototype wax model was fused to the base of theduplicator and the assembly was completed by securing the container over thebase portion of the plastic duplicator. The base and the catalyst portion of theduplicating silicone material (KalSil Duplicating Silicone, Kalabhai, Mumbai,India) were mixed according to the manufacturer's instructions andpoured over prototype wax model. After the set of the silicone material wasverified, prototype model was retrieved from the duplicating silicone mold.

A slit opening was made on one of the walls of the mold to facilitate easyremoval of wax specimens. The duplicated siliconemold of the prototype waxmodel will be used in preparing wax specimens of uniform dimension with thedenture tooth. These wax specimens will be subjected to processing with theinjection molding acrylic resin.

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

The ridge lap area often acrylic denture teeth (n=10) were subjected tosand blasting using 110μm aluminium oxide (Korox, Bego, Germany)The teeth were air abraded held at a distance of 10mm from the nozzle,maintaining the pressure at 2psi for a period of 30 seconds following whichthey were cleaned using a steam cleaner and the same procedure werefollowed for all the ten denture teeth.**(Figure 1)**

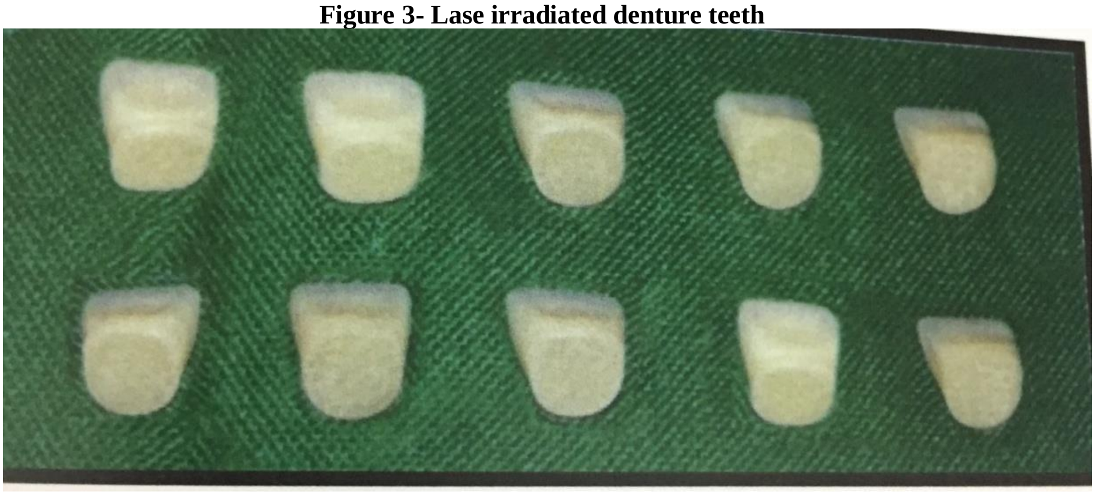
Figure1- Sandblasted denture tooth

The ridge lap area of ten acrylic denture teeth (n= 10) were coated withchemical bonding agent (Poly link IC ,Bredent, senden, germany) asper manufacturer's instruction. It is a methylmethacrylate based adhesiveagent used during the processing of acrylic dentures. Three covering coats ofchemical bonding agent were applied to the ridge lap surface using anapplicator with an application time of 30 seconds for each coat. The final coatof bonding agent was applied shortly before injection molding process andcare was taken such that there was no contamination of the ridge lap area afterapplication of bonding agent. The similar steps were done for all the tendenture teeth**.(Figure 2)**

Figure 2-Bonding agent treated denture teeth

The ridge lap area of ten acrylic denture teeth (n=10) were surfacetreated with anEr, c r:YSGG laser system (WaterlaseiPlus laser unit, BiolaseTechnology, CA, USA). Laser irradiation was done on ridge lap areaof acrylic denture teeth operating at the wavelength of 2.78µm, pulse durationof 700µs and repetition rate of 10 Hz. The power output was set at 3W accordingto test protocols. The air and water sprays from the handpiece wereadjusted 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 laserbeam was aligned to the ridge lap acrylic surface perpendicularly at thedistance of 10mm . The area to be bondedwas 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 teetheach according to the type of surface treatment rendered on the ridge lap areaof those denture teeth.
The denture teeth were divided into four groups as follows:
1. Group I (n=10) Untreated acrylic denture teeth. (Control group)

2. Group-II (n=10) Sandblasted acrylic denture teeth. (Sandblastedgroup)
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 (Laserirradiation Group)

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

Four denture teeth comprising of one representative from each groupwere subjected to 3-D surface profile scanning. Surface roughness wasmeasured using 3-D Non-contact Surface Profilometer (TalysurfCCI, Ametek,Uk). The average surface roughness (Ra) value of each denture toothwas obtained. The magnification of the optical lens was 50x. Each denturetooth was placed under the objective lens and photomicrograph at 50xmagnification to obtain 3-D and advanced 3-D views using AdvancedAspherics Analysis Software.

The selected acrylic maxillary left central incisor denture tooth of eachgroup 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 hadhardened, the wax specimen was retrieved from the silicone mold. Thus, fortysuch wax specimens. were obtained for the four groups of denture teeth.**:**

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

A special two compartment thermal insulating flasks was used for theinjection molding system. Model plaster (Kaldent, Kalabhai,Mumbai, India) were mixed according to the manufacturer'srecommendations and were filled into lower compartment of the flask.Wax specimens were positioned in the flask such that the base ofthe wax specimens were embedded in the model plaster. All thewax specimens were connected to one another using wax channeland were finally sealed to main channel. This was done to ensurecontinuity in the flow of the resin. A separating fluid (Ivoclar,Vivadent, Liechtenstein) was applied onto the plaster surface asper manufacturer's recommendation and flasking procedure werecompleted with the counter pour. After de-waxing, bonding surfaces ofthe teeth were scrubbed with detergent, rinsed with clean boiling waterand 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 ridgelap surface of the acrylic teeth according to the manufacturer'sinstruction. Three covering coats of bonding agent were applied to theridge lap surface using bonding agent applicator with the applicationtime 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 polymerand 30 ml monomer of SR Ivocap Plus (lvoclarVivadentInc,Liechtenstein, Germany) **(Fig. 4**) was used. The monomer was pouredinto 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 clampingframe, in a hydraulic press. The material was injected into the moldunder 6 bar of pressure for 5 minutes with the manufacturer's pressureapparatus. Then the SR Ivocap assembly was placed polymerizationbath. The temperature of the water bath was set at 100° C in such away that the water boiled during the entire period. The polymerizationperiod (begins with the boiling of water) was 35 minutes. After thepolymerization period, SR Ivocap assembly was removed from theboiling water and immediately placed in cold water.

Figure 4- SR Ivo cap High impact, Pink

After 20 minutes the pressure apparatus was removed but clampingframe together with flask remained in cold water for an additional 10minutes.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 wereprepared in the similar manner.

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

A total of forty test samples (Group I, II, III and IV) were tested forshear bond strength in a universal mechanical testing machine (Lloyd'suniversal testing machine, U.K.) (Fig.28) at the Department of PolymerTechnology, Central Institute of Plastic Engineering Technology Guindy,Chennai, India**.(Figure 5)**

Figure- 5 Fortyacrylised test samples

A 2mm groove was placed with a straight fissure bur on the palatalaspect of the denture teeth at the bonding interface between the acrylic teethand acrylic resin block so as to facilitate proper seating of the testing chiseland to prevent it from slippage during application of the load. Test sampleswere fixed to the sample fixture at the bench vice of the machine with themono beveled chisel blade placed flat against the 2 mm groove on the palatalaspect of denture teeth.

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

Bond strength (MPa) = load (N) + surface area (mm^2)

The results were tabulated and subjected to statistical analysis. TheSPSS (SPSS 16 for Windows 8.0, SPSS Software Corp., Munich, Germany)software package was used for statistical analysis. Mean and standarddeviation were estimated from the results obtained from each sample for eachstudy 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 wasdetermined for every test sample by visual examination by a single operatorand was categorized into one of three categories as adhesive, cohesive andmixed failure. [11,19,27,56]

III. Results

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

Sample No.	Shear bond strength (MPa)
1	28.1
2	33.3
3	24.9
4	29.4
5	30.5
6	28.5
7	32.1
8	27.9
9	34.1
10	31.8
MEAN/SD	**30.06/2.83**

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)

Sample No.	Shear bond strength(MPa)
1	35.6
2	36.9
3	33.4
4	29.1
5	37.4
6	31.4
7	30.5
8	38.7
9	34.7
10	27.5
MEAN/SD	**33.52/3.77**

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)

Sample No.	Shear bond strength(MPa)
1	37.7
2	44.4
3	36.5
4	40.5
5	48.1
6	43.8
7	46.9
8	36.2
9	47.9
10	42.4
MEAN/SD	**42.44/4.56**

Inference:
The maximum shear bond strength is 48. l 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)

Sample No.	Shear bond strength(MPa)
1	33.2
2	35.7
3	30.5
4	37.8
5	29.8
6	40.1
7	38.5
8	42.3
9	36.5
10	32.7
MEAN/SD	**35.71/4.12**

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

Groups	Mean shear bond strength (MPa)	Standard deviation	'p' value
Group I	30.06	2.83	0.001*
Group II	33.52	3.77	
Group III	42.44	4.56	
Group IV	35.71	4.12	

*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)

Groups	Mean shear bond strength (MPa)	'p' value
Group I	30.06	0.209
Group II	33.52	
Group I	30.06	0.001*
Group III	42.44	
Group I	30.06	0.013*
Group IV	35.71	
Group II	33.52	0.001*
Group III	42.44	
Group II	33.52	0.592
Group IV	35.71	
Group III	42.44	0.001*
Group IV	35.71	

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 onlyon the expertise of the operator, but also on nature and properties of dentalmaterials involved in denture fabrication. The three most important requisitesfor a predictable functioning of the removable dental prosthesis mainly theteeth bearing portion are hardness/wear resistance, durable bond strength tothe denture base resin and color stability.[5] The bond strength of artificial teethis paramount for the longevity of removable prosthesis especially in situationswhen maxillary complete denture opposes natural dentition, fixed dentalprosthesis and implant supported restoration.[8,19,35]

It has been estimated that between 22% - 30% of denture repairsinvolve tooth de-bonding, [2,3,22,27,28,34]usually in the anterior region of thedenture. [3,13,20,22,26,27,42]This detachment may be attributed to a lesser ridge lapsurface area available for bonding in the anterior region, mechanical fatigueand the direction of the stresses from repeated chewing and accidentalfalling.[3,8,22]The major parameters affecting the bond strength are acrylictooth material, surface modification of ridge lap area and composition ofdenture base resin.[1]

The mode of attaining a bond between the acrylic teeth and the denturebase resin involves, the polymerizing denture base resin must come in physicalcontact with the denture tooth resin and the polymer network of denture baseresin must react with acrylic tooth polymer to form an interpenetrating polymer network (IPN) .[3,11,] de-bonding may be the result of incompatiblesurface conditions at the tooth and base interface.[3]

Majority of the manufacturers produce teeth and denture base resinwith little or no mention of the bond strength or compatibility between teethand base materials which could have an influence on the durability and repairpotential.

Several methods have been employed to enhance the bonding ofacrylic resin teeth to denture base which can be either mechanical or chemicalmodification of ridge lap portion or a combination of both. Mechanicalmethods can be further categorized into macromechanical andmicromechanical. [19]Macromechanical means of altering the tooth bondingsurface includes grinding the glazed surface, placements of vertical andhorizontal grooves and diatorics .[7.11.13.18] Micromechanical surface alterationsinclude high energy air abrasion with 50μm, ll0μm or 250μm aluminiumoxide. [1,13,20,25,26]

In removable prosthodontics air abrasion with Al_2O_3 is theconventional surface treatment procedure done on the intaglio surface ofdentures before relining procedures to enhance mechanical bonding.[29]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.[13,18,20,23,43,]

Chemical method of surface conditioning the bonding surface employs the application of monomer, non polymerizable solvents such asdichloromethane, acetone and chloroform[7,9,11,18,23,30]The application ofchemical bonding agent is commonly preceded by a slight mechanical surfacemodification as recommended by manufacturer. Most of the chemical solventsfacilitated the swelling of denture tooth polymer ·and thereby enhancing thediffusion of polymerizable materials, mainly MMA, from the denture baseresin.[12,23]This improves the extent and quality of the inter-penetrating networkafter the completion of polymerization.

The use of lasers in dentistry has widened its application as a means ofaltering the surface characteristics of the material's bonding interface.In removable prosthodontics surface irradiation using laser is considered asone of the mechanical method of surface modification at the bonding interfaceof restorative material.[29] Similarly in fixed prosthodontics surface lasing onthe metal substructure has been advocated before porcelain addition in orderto augment metal-ceramic bond. In implant prosthodontics laser surfacetreatment is utilized as one of the surface modification method to enhancecontact between bone and implant thread surface. Studies demonstrating theuse of laser irradiation as a surface treatment modality on the ridge lap portionof acrylic tooth bonded to PMMA denture base resin are sparse.[1,27]

Type of denture teeth used can also affect the integrity of the bondwhen processed to acrylic resins. [22]Denture teeth are primarily composed ofpolymethylmethacrylate and have been increasingly modified to improve theirphysical property by incorporating cross-linking agents, using differentmonomers and addition of fillers. [5,26] Cross-linking agents are generally usedto improve properties such flexural strength, hardness, wear resistance, crazeresistance which help increase prosthesis longevity.[8,26]Bond strength ofartificial tooth resin to denture base resin has been related to the ability ofmonomer to diffuse into the tooth resin.[8,12,13,22,23]This is significantly affectedin cross linked teeth due to its highly condensed matrix, hampering thediffusion of monomer into the matrix,[18,44,35,42,23,26] therefore ridge lap portion ofthe acrylic teeth is expected to be less cross linked so as to facilitate bondingto the denture base resin. [8,12,20,26]

The method of processing of acrylic dentures could also influence thebond between the teeth and resin denture base. [13]Compared to the conventionalcompression molding technique, injection molding does not have any heatconduction, leading to the rise in polymerization temperature thereby resultingin increased rate of monomer diffusion from the denture base polymer mixtureinto the acrylic teeth polymer,[6,12,13] which is a prerequisite for the formation ofInterpenetrating polymer network (IPN). Moreover injection molded denturebase acrylic system results in negligible change in dimensions and verticaldimension of occlusion.[45]

In vitro studies have been done to evaluate the bond between acrylicdenture teeth and acrylic denture base resin subjected to conventional surfacetreatments like air abrasion, placement of grooves, application of chemicalbonding agents etc. [7,11,16,18,22,23]However studies reporting on the efficacy oflaser surface irradiation on shear bond strength are lacking, also there is apaucity 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 ofacrylic teeth bonded to denture base resin is 31 MPa. [20,] In the present studythe shear bond strength values of all the test groups exhibited higher valuethan the recommended.Chemical bonding agent treated samples (42.44 MPa) showedsignificantly higher bond strength compared to control (30.06 MPa),sandblasted samples (33.52 MPa) and laser irradiated samples (35.71MPa)('p' < 0.05).

The highest shear bond strength value produced by chemical bondingagent surface treatment for Group III could be explained on the basis thatmethylmethacrylate based bonding agent applied to the ridge lap portion before acrylisation provided a solvent effect on the tooth surface, thereby increasing the wettability and favouring a more effective diffusion of themonomer present in the denture base polymer across the tooth denture baseinterface and resulting in the formation of a durable interpenetrating polyrnernetwork.[8,13,21,40] Another factor that could have an effect on the bondinginterface is the method of processing, injection molding technique results in anincrease in polymerization temperature which is conducive for higherdiffusion of monomer from the denture base polymer resulting in higher bondstrength.[6,8,12,13,22]

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 asthe main ingredient. Three covering coats of bonding agent were applied,with the application time of 30 seconds for each coat. Rached et al[19] andSarac et al[47] have stated that an application time of 30 seconds was found tobe effective in increasing the bond strength. Hence, an application time of30 seconds was used in the present study. In addition, Vallitu et al[52] had alsostated that the time lapse between the application of chemical solvent andpacking could influence the bond strength. Longer time lapse results inevaporation of the chemical solvent from the ridge lap area, allowing littlesolvent interaction with the monomer from the denture base resin. Shorter thetime interval will produce better bond formation. Therefore the final coat ofbonding agent was applied shortly before the injection process in this study.

The probable reason for the highest bond strength in chemical bondingagent group is that the application of chemical bonding agent dissolves part ofPMMA of the tooth and provides free double bonds, that may co-polymerisewith the PMMA of the denture base resin, forming a durable interpenetratingpolymer network (IPN) structure, improving the bond between the tooth andacrylic resin. [22,27,49] The results obtained in the present study were similar to theresults of Saavedra et al[8] (38.0 MPa), Lang et al[42] (36 MPa) and Fletcheret al.[48]

Various other chemicals were employed in the previous studies.[7,22,23]Takahashi et al[25] reported the application of dichloromethane as a chemicalbonding agent and achieved a significant improvement in bond strength ofacrylic 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 lesserwhen compared to chemical bonding agent treated samples (42.44 MPa)('p' < 0.05). The bond strength was higher than sand blasted samples withoutany statistical significance (33.52 MPa) ('p' > 0.05).

Laser application may cause some chemical changes on the acrylicsurface because of thermal degradation. This can be explained by the highenergy produced by Er,Cr:YSGG laser. The energy produced by this laser isdue to the interaction with the water droplet at the bonding surface in order tocreate the water molecule excitation resulting in micro-expansion andpropulsion. An increased surface area may be formed by this expansion whichcauses the surrounding material to ablate. [29] These events are believed to beresponsible for the increase in the bond strength values when compared tosandblasting and untreated (control) group.

Akin et al[27]reported that altering the PMMA surface by Er:Y AG lasersignificantly improve the bond strength in PMMA/silicone specimens and alsodemonstrated that other laser systems like Nd:YAG and KTP laser areineffective in strengthening the bond. He also reported that Er:YAG lasertreatment at 10 Hz, 3W and 300 mJ with long pulse duration was shown to beeffective method of improving the bond strength of UDMA and liners. Thepresent study followed the same parameters used for Er: Y AG laser as adaptedby Akin et al.[27]

The shear bond strength of sandblasted samples (33.52 MPa) washigher than control samples (30.06 MPa) and lesser than laser irradiatedsamples (35.71 MPa) but does not have statistical significance ('p' $>$ 0.05).The shear bond strength was significantly lesser than chemical bonding agenttreated samples (42.44 MPa) ('p' < 0.05). Air abrasion using alumina particles on the ridge lap portion of theacrylic teeth increased the surface energy and surface roughness, therebytile wettability of the monomer from the denture base polymer matrix.[20]

Sandblasting with different grits of aluminium oxide has been employed in the literature. A study done by Barpal et al[20] revealed thatsandblasting the ridge lap area with 50µm could only remove the glaze on theridge lap area but had no significant effect in improving the bond strengthbetween the denture base resin and acrylic resin teeth. Most of the studiesreported that grit size in the range of 120 µm Al_2O_3 particle is adequate toimprove the bond strength. [1,21,27]

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

The values obtained in the present study for sand blasting group weresimilar to the results of Geerts et al[32](32 MPa) and Nishigawa et al.[34]various studies have reported that bond between denture teeth anddenture base also depends on the processing technique and type of resinemployed. [13,18,38,47] In the present study heat curing injection molding techniquewas employed for acrylization using SR Ivocap high impact resin.

Vallitu et al[6] in his study concluded that heat curing is the bestprocedure to obtain good bonding between acrylic denture teeth andpolymethylmethacrylate denture base polymer. He stated that increasedpolymerization temperature that enhances the more diffusion of monomer isthe attributing factor. Numerous studies have shown that injection moldingtechnique has advantage of less polymerization shrinkage thereby producingaccurate denture. [36,37,39,45,52] Furthermore, the pressure used to inject the acrylicdough might enhance the diffusion of monomer from the denture base acrylicresin into the acrylic resin polymer of the tooth [12]

Cunningham et al [9] demonstrated that highimpact heat cured resin shown to have better bond to cross linked teeththan a conventional heat cure resin. Similar result was shown byFletcher et al,[48] Huggett et al[12] and Morrow et al.[15]

The effect of thethermocycling on the bond strength was also evaluated in the present study. Thermocycling is used to closely simulate the oralconditionand to assess the durability of bond.[10,40]All the test samples were subjected tothermocycling for 1000 cycles between 5° C and 55° C with the dwell time of20 seconds. Various studies have reported that thermocyclingdecreased thebond strength between denture teeth and acrylic resin of all polymerization methods.[2,3,7,19,40] Amin et al[57] in a study demonstrated that deterioration of thebond 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 onerepresentative denture tooth sample from each test group was evaluated using3-D Surface Profilometer. The highest average surface roughness ,valueWas exhibited by denture tooth sample surface treated by laser irradiation(Group IV) (Ra- 1.70µm) followed by denture tooth sample surface treated bySand blasting (Group II) (Ra-1.58µm) followed by denture tooth sample surfacetreated by chemical bonding agent (Group III) (Ra-0.62µm).The least average roughness valuewas 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 laserIndicated denture tooth could be based on the fact that the depth of penetrationby the laser energy yields increased area of rough surface as evidenced bywell-defined peaks and valleys when examined under advanced 3-D imaging.The surface topography of sandblasted denture tooth is due to the highenergy abrasive action of alumina particles resulting in better penetration ofthe substrate surface.

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

Figure 6- 3D surface texture analysis of untreated denture tooth of Group1

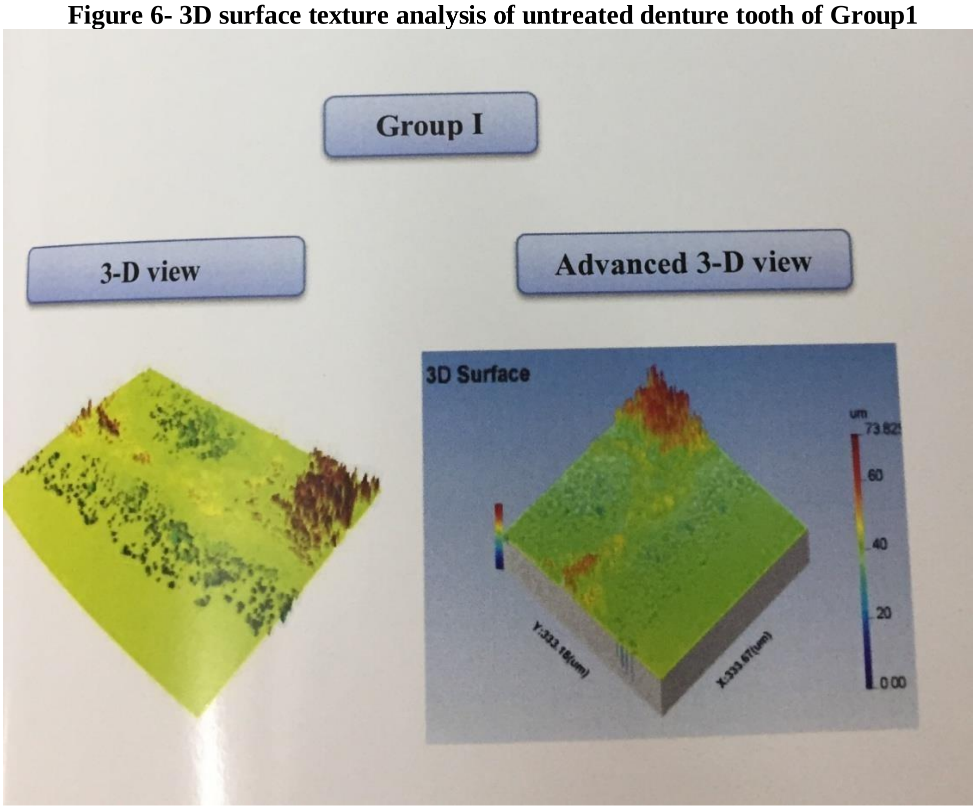


Figure 7- 3D surface texture analysis of sandblasted denture tooth of Group 11

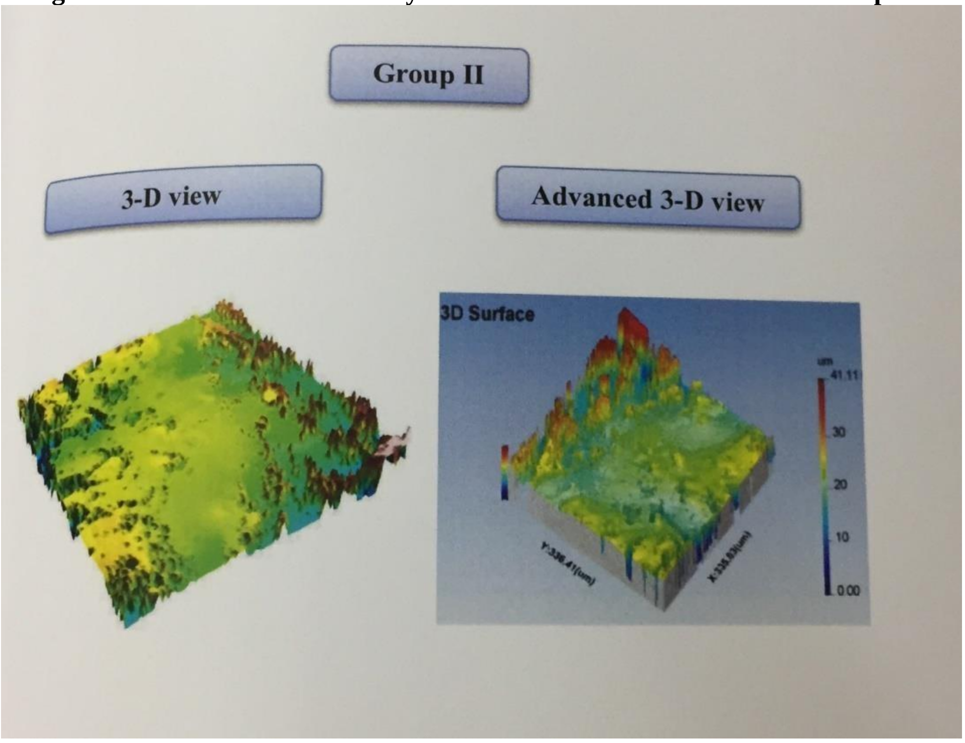


Figure 8-3D surface texture analysis of chemical bonding agent treated denture tooth of Group111

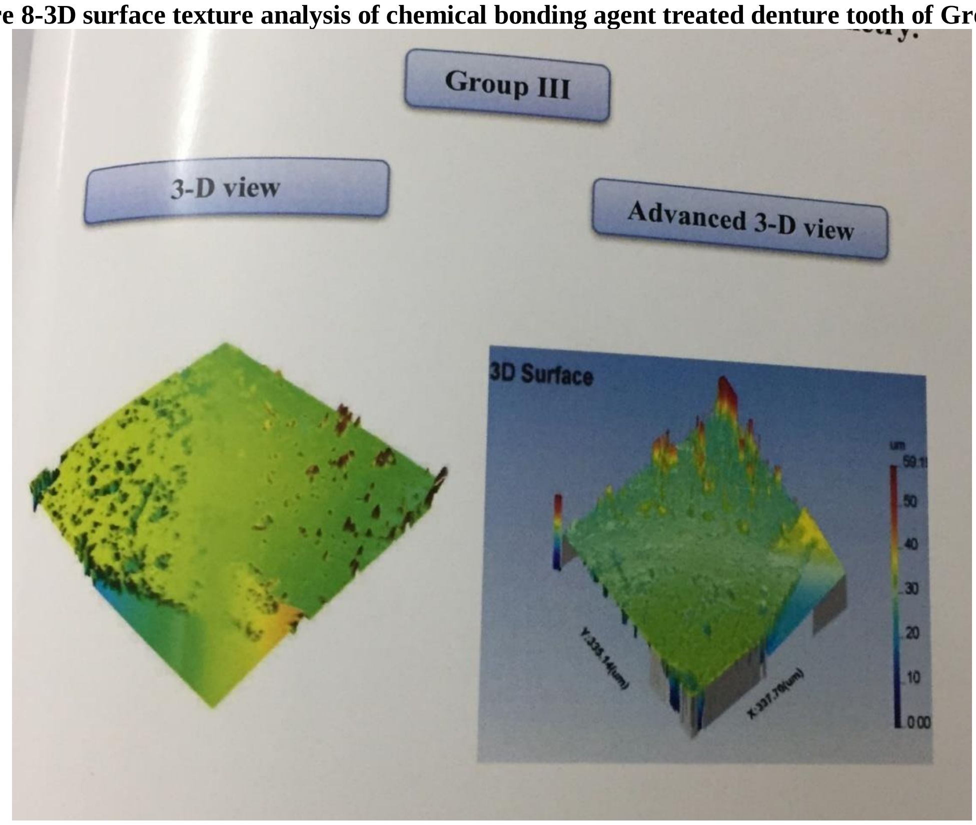
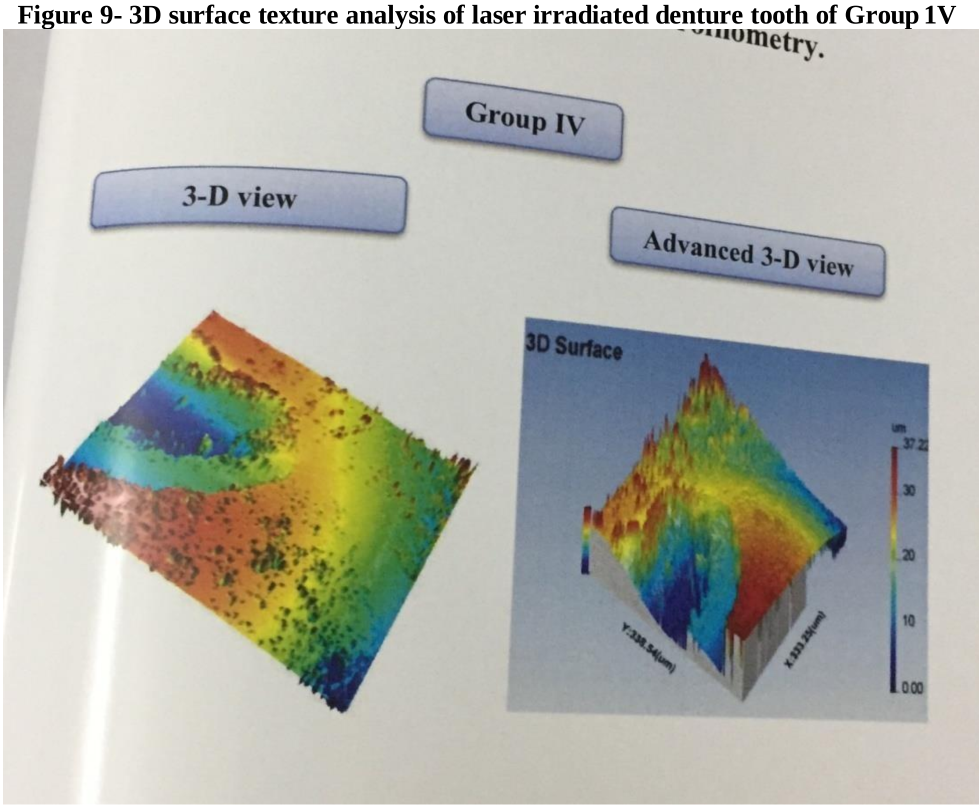


Figure 9- 3D surface texture analysis of laser irradiated denture tooth of Group 1V



The type of failure also needs to be considered because fracture mayoccur in the denture tooth before occurring at the interface between toothand denture base. Bond failures could be adhesive, cohesive or mixedfailure.[1,11,31,35]In the present studymost of the failures that occurred were mixed type of failure.

Group I samples exhibited predominantly adhesive failure. In Group II majority of samples exhibited adhesive failure and remaining samples exhibited mixed failures with predominant adhesive patterns. The mode offailure observed in Group I and Group II samples are suggestive of weakerbond strength as Group I samples were not rendered any surface treatmentand sandblasting created only shallow surface irregularities in Group II.Group III and Group IV samples exhibited predominantly cohesive failures Followedby mixed failures with predominant cohesive patterns. This indicates Betterpenetration of MMA into acrylic tooth polymer forming a durableinterpenetrating polymer network and higher roughness caused by laserirradiation ensuring better bond in Group IV, which reflected in their highervalues 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 thegroups tested. This is in correlation with the least Ra value obtained and theadhesive failure observed, which indicates a weaker bond.

Sandblasted samples (Group II) demonstrated a marginal improvementin shear bond strength over Group I, but lesser when compared to Group IIIand Group IV. This moderate increase is attributed to the higher Ra value ascompared to Group I. The marginally lower shear bond strength valueobserved for Group II as compared to Group IV could be attributed to thebetter surface roughness obtained by laser surface treatment (Group IV) and also the predominantly adhesive modeoffailure observed in the group II samples.

Group III produced highest shear bond strength value among all thetested groups. The cohesive and mixed mode of failure was seen in thesamples. Although the surface roughness value of the chemically treateddenture tooth was lesser than the sandblasted and laser treated denture tooththe significantly higher shear bond strength values obtained could be attributedto the chemical action of the bonding agent.

Laser surface treated samples Group IV revealed higher shear bondstrength value than Group I and Group II but lesser than Group III. The resultsderived from the shear bond testing for Group IV arc in concurrence with theobservations from surface profilometry and also the cohesive and mixed typeof 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 aftersubjecting 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.

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