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Research Article

An Evaluation on Effect of Surface Treatment and Mechanical Modifications on Shear Bond Strength between Acrylic Denture Teeth and Heat Cure Acrylic Denture Base Resin

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Abstract

Statement of Problem: Debonding of acrylic denture teeth from denture base remains a major problem in prosthodontic practice. Attempts to improve the bond strength have involved several surface treatment and modifications on the ridge lap surface of the denture teeth. However, conflicting findings have been reported in the literature regarding the improvement of bond strength.

Purpose: The purpose of this study is to compare shear bond strength between acrylic denture teeth and heat cure denture base resin with different surface treatment and modifications.

Materials and Methods: Acrylic denture teeth (New ACE, Yamahachi, Japan) and heat cure denture base resin (Trevalon, Densply, India) were the materials selected for the study. 50 specimens were divided into 5 groups (n = 10) depending upon different surface treatments and modifications; Group A (control): Untreated without gingival extension of acrylic to cervical collar of tooth, Group B: Untreated with gingival extension of acrylic to cervical collar of tooth, Group C: Painting the ridge lap surface of the teeth with monomer, Group D: Sandblasting of ridge lap surface with aluminum oxide particles, and Group E: Preparing a diatoric. All specimens were subjected to shear bond strength testing in UTM. A shear point load was applied at an angle of 135^0, at a crosshead speed of 5 mm/min, until failure and the shear load required to break specimen was recorded. Fractured surfaces were examined to determine mode of failures.

Result: Data were analyzed with one way ANOVA for multiple group comparisons followed by Tukey post hoc for group comparisons ($p < 0.05$). Mean shear bond strength value for Group A was 161.40 N, Group B 273.40 N, Group C 450.40 N, Group D 535.10 and Group E 397.30 N. Multiple group comparison showed a statistically significant difference between groups A, B, C, D and E (F= 254.309, $P < 0.001$). This suggested, the greatest bond strengths for specimens treated with sandblasting and lowest strengths for untreated specimens without extension of acrylic to cervical collar.

Conclusions: Surface treatment and mechanical modifications of ridge lap surface of acrylic denture teeth resulted in significant improvement in shear bond strength between acrylic denture teeth and heat cure acrylic denture base resin.

Clinical Implications: Surface treatments and modifications significantly improve bond strength values. A little extra effort during denture processing can save the dentists from humiliation of repeated repairs and save their valuable time.

Keywords: *Debonding, Bond Strength; Polymethylmethacrylate; Acrylic Teeth; Ridge Lap Surface*

Introduction

Acrylic resin is widely accepted as denture base material due to its simple technique, easy manipulation, good esthetic, low specific weight, low solubility in oral fluids and low cost [1]. Acrylic teeth have several advantages which include chemical bonding with acrylic denture base, ease of adjustment, reduced cost, higher shock absorbability and minimal abrasion of opposite dentition [2]. One of the major drawbacks of these teeth is their debonding from the resin denture bases [3-7]. A study has shown that 33% of the repairs carried out are for deboned or detached teeth from denture base [4].

Several factors related to denture fabrication compromise the bond strength at the interface which includes entrapment of air-bubbles, contamination of the bonding surface and other processing parameters [5-7]. Attempts to improve the bond strength has involved several chemical treatments and mechanical modifications on the ridge lap surface of the denture teeth. However, conflicting findings have been reported in the literature regarding the improvement of bond strength with such treatments [5,8-45].

Adhesion between denture teeth and the denture base is an important factor for the integrity of the prosthesis and methods to provide optimal bond strength of the denture tooth to the denture base has to be considered. Hence it was the aim of this study to investigate the effect of the different surface treatments and modifications of ridge lap area of acrylic denture teeth on the shear bond strength between acrylic denture base resin and acrylic denture teeth. The null hypothesis was based on the assumption that surface treatments and modifications would not improve the shear bond strength.

Materials and Methods

50 Test specimens consisting of acrylic denture teeth attached to heat cured PMMA (polymethyl methacrylate) were divided into 5 Groups (n = 10) depending on different surface treatment and modifications (Table 1). In Group A, no surface treatment was done and acrylic resin was not extended to cervical collar of tooth (Figure 1). In Group B, no surface treatment was done and acrylic resin was extended to cervical collar of tooth (Figure 2). In Group C, application of the heat cure monomer (Trevalon, Dentsply) was done for 1 minute on the ridge lap surface of the teeth, with a monomer applicator tip before packing resin dough into the mold (Figure 3). In Group D, the ridge lap surface of acrylic denture teeth was sand blasted with 50 µ aluminum oxide powder, at controlled distance of 10 mm for 30 seconds under 5 kg/cm2 of pressure (Figure 4). In Groups E, the diatoric was prepared by grinding into the ridge-lap with a round bur (Meisinger Carbide Burs US #4, HP 014) with dimensions of 1 × 2 mm2 (Figure 5).

Group	Surface Treatment
A	Untreated without gingival extension of acrylic to cervical collar of tooth
B	Untreated with gingival extension of acrylic to cervical collar of tooth
C	Painting the ridge lap surface of the teeth with monomer
D	Sandblasting of ridge lap surface with 50 µ aluminum oxide particles
E	Preparing a diatoric recess 1 × 2 mm^2

Table 1: *Surface treatments and modifications.*

Figure 1: *Acrylic is not extended up to cervical collar of the tooth.*

Figure 2: *Acrylic is extended up to cervical collar of the tooth.*

Figure 3: *Painting of monomer on ridge lap surface.*

Figure 4: *Sandblasting of the ridge lap surface.*

Figure 5: *Preparation of diatoric in ridge lap surface.*

Preparation of Experimental Specimens

Right Maxillary Central Incisor was selected from acrylic denture teeth set (New ACE, Yamahachi) and attached to a triangular wax block of size 2.5 x 2.5 x 1.5 cm3 (Figure 6). This wax block was pressed in to polyvinyl siloxane putty material (Elite HD+, Zhermack) to-make the index which was used for fabricating 50 identical wax models (Figure 7).

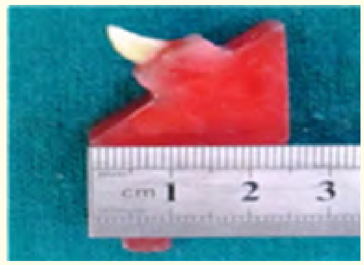

Figure 6: *Standard wax block.*

Figure 7: *Silicone index.*

After removal of wax from ridge lap surface, denture teeth were placed in the silicone index, which was filled with modeling wax, melted in a wax bath. After cooling, the specimens were removed from the silicone mold, and any excess from around the teeth was removed using magnification loupe. 50 specimens were fabricated in a similar manner and stored in distilled water. The prepared wax models were invested with a type III dental stone (Kalstone, Kalabhai) (Figure 8). Dewaxing was done and a thin film of sodium alginate separating media (Cold Mould Seal, DPI) was applied to the mold space except the ridge lap surface of teeth (Figure 9). Acrylic was packed in mould in dough stage and flasks were kept under 20 KN of pressure using a hydraulic press and kept for 30 minutes for bench curing. Water bath curing was carried out in a thermostatically controlled water bath using short curing cycle. Following the bench cooling procedure, the flasks were opened and the specimens were carefully retrieved. Trimming and finishing of specimens were done in conventional manner. All specimens were stored in distilled water for 72 hours following acrylization.

Figure 8: *Investment of wax block.*

Figure 9: *Dewaxing.*

Shear Bond Strength testing

Shear bond strength was tested in UTM (Shimadzu) using a 100 KN load cell. A shear point load was applied at cingulum of central incisor at a 135^0 by means of a cylindrical stainless steel pin, 1 mm in diameter, at a crosshead speed of 5 mm/min (Figure 10). The specimens were loaded until fracture (Figure 11) and the shear strength required to break specimen was recorded from the digital monitor attached to the testing machine.

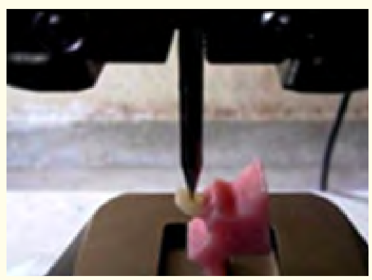

Figure 10: *Shear bond strength testing.*

Figure 11: *Sheared specimen.*

In order to simulate a clinical situation, a shear load was applied at cingulum of central incisor at an angle of 135^0 to its long axis. This angle was chosen to simulate the average angle of contact between maxillary and mandibular anterior in class I occlusion. The studies by Meng [20], Takahashi [21] and Madelyn L Fletcher Stark [22] used similar angular forces to stress their test specimens. The bond surface area was not calculated due to the complexity of curve and irregular shape of original teeth's ridge lap and cervical area.

The fractured surface of the sheared specimens was analyzed visually with magnification loupe (x5 magnification) to determine the modes of failure which was categorized into adhesive, cohesive and mixed type.

Data were entered on SPSS Ver 20. Since the data were of the continuous type, parametric tests were used for analysis. Mean and Standard Deviation (SD) were calculated. Data were normally distributed. So, one way Analysis of Variance (ANOVA) using F test statistic of the data, were carried out for testing significance of the differences in the mean values for multiple group comparisons followed by Tukey post hoc for group wise comparisons. All results were considered statistically significant if $P < 0.05$.

Result

Mean shear bond strength value for Group A was 161.40 N, Group B 273.40 N, Group C 450.40 N, Group D 535.10 and Group E 397.30 N (Figure 12). Multiple group comparison showed a statistically significant difference between groups A, B, C, D and E ($F = 254.309$, $P < 0.001$) (Table 2, 3). This suggested the greatest bond strengths for specimens treated with sandblasting and lowest strengths for untreated specimens without extension of acrylic to cervical collar (Table2, 3).

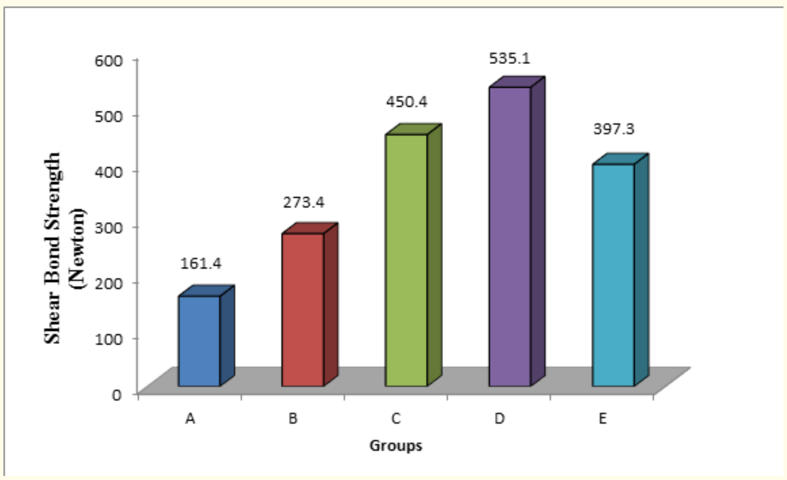

Figure 12: *Comparative analysis of Mean SBS (Newton) values for all groups.*

SBS	Sum of Squares	df	Mean Square	F	P
Between Groups	871030.280	4	217757.570	254.309	.000
Within Groups	38532.200	45	856.271		
Total	909562.480	49			

Table 2: *One way ANOVA.*

(I) Group	(J) Group	Mean Difference (I-J)	Sig.
A	B	-112.00000*	.000
	C	-289.00000*	.000
	D	-373.70000*	.000
	E	-235.90000*	.000
B	C	-177.00000*	.000
	D	-261.70000*	.000
	E	-123.90000*	.000

C	D	-84.70000*	.000
	E	53.10000*	.002
D	E	137.80000*	.000

Table 3: *Multiple Comparisons Tukey HSD.*

Regarding failure modes, 18 % of specimens failed adhesively, 30 % failed cohesively and 52% showed mixed failure (Figure 13). Adhesive failure decreased with surface treatments and mechanical modifications. Most of specimens in group D displayed cohesive failure (90%). In group C most of the failure observed was of mixed type (80%). None of the specimen in group C, D and E showed adhesive failure (Figure 14).

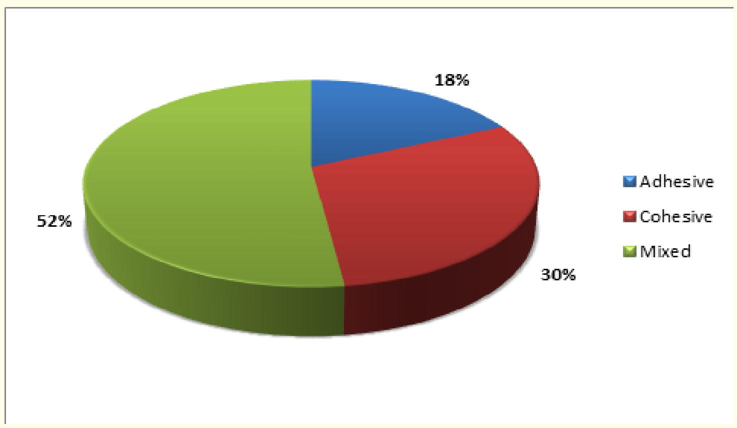

Figure 13: *Comparative analysis of mode of failures in different groups.*

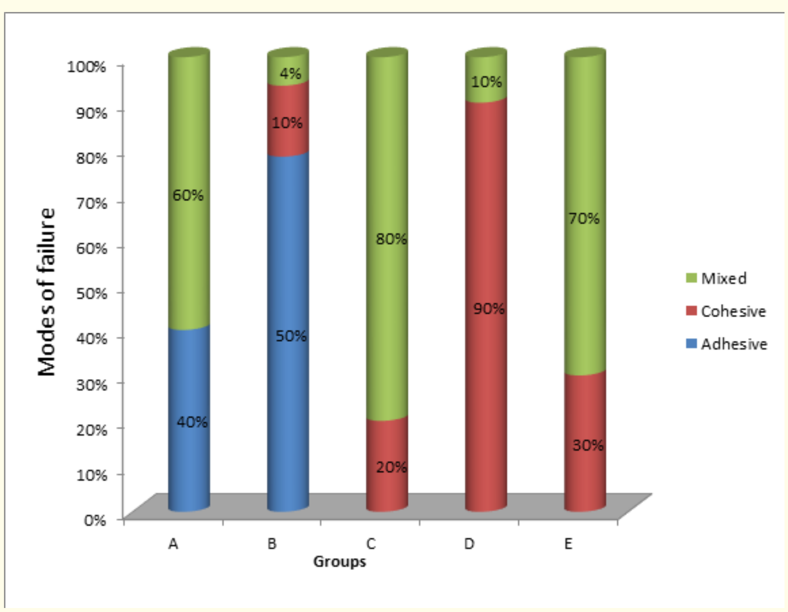

Figure 14: *Mode of failures in each group.*

Discussion

Denture tooth debonding is an ongoing concern in prosthodontic practice. It has been estimated that about 30% of denture repairs involve tooth debonding.4,6 With the increased use of implants and the commensurate increase in forces applied to prosthetic components it is probable that debonding will become an even greater clinical problem in the future [7].

Attempts to improve the bond strength of denture teeth to acrylic resin denture base has involved several chemical treatments and mechanical modifications on the ridge lap surface of the denture teeth [3,5,8-11]. Huggett [6] and Cardash [12] demonstrated that preparation of retention grooves in the ridge lap surface of the acrylic teeth did not improve bond strength. Fletcher [13], Spratley [14] and Cardash [15] have shown an increase in bond strength by grinding a diatoric recess. Spratley [14] and Morrow [16] determined that painting unmodified ridge laps of plastic teeth with monomer actually decreased bond strength. Geerts and Jooste [17] and Saavedra [18] demonstrated significantly higher bond strengths when painting the denture tooth surface monomer. Chung [19] showed that airborne-particle abrasion of denture tooth increased bond strength. Saavedra [18] found such surface treatment to be insignificant.

There is a wide variation in the materials tested and the methodology used for constructing and testing the samples for bond strength [7,23]. The studies for determining the adhesive bond strength includes tensile loading according to, or approximating ADA 15, compression/ shear loading, transverse loading, according to BS 3990, dye penetration approach, and finite element stress analysis study.

The tensile loads used in many artificial tooth bond strength studies are not representative of real clinical conditions. The expulsive anatomic shape of anterior teeth and the direction of occlusal forces make the occurrence of significant tensile forces over these teeth unlikely. On the other hand, especially the angulated shear and compressive loads are much more plausible clinically [3,12]. The shear compressive load testing has been adopted as a method of analyzing bond strength between denture tooth and acrylic resin denture base in various researches [17,18,20,24,25].

Cunningham [23] criticized the approach for determining the bond strength of plastic denture teeth using the standard specifications, ADA 15 and IS0 3336. In the former, posterior teeth only can be evaluated because of the specimen dimensions, yet, in practice, anterior teeth are more prone to be displaced from the denture base. Further, the need to machine the tensile specimen subsequent to processing would introduce stresses at the tooth-base interface and so adversely affect the test results. Using the method described in IS0 3336 a more clinically correct test specimen is produced. However, the tensile shear loading system employed in this method together with the varying tooth bonding surfaces does not allow quantitative results to be obtained.

The Japanese standard JIST 6506 attempts to overcome this problem by using a single tooth form as its specimen. In our study, single anterior tooth (maxillary central incisor) has been used to fabricate test specimens.

Maximum bite force, exerted by complete denture wearers, is commonly low, which is approximately 90 N. The shear bond strength of the tooth/denture base bond shown in this current study exceeds the magnitude of the force necessary for chewing foods. Thus, bond strength in all the specimens seems clinically adequate.

Comparing our results to other investigators poses difficulties; because of method differences and the difficulty in isolating the variables in each of the 5 treatment groups, yet some comparisons show interesting similarities.

Effect of extension of Acrylic up to cervical collar of tooth

The A.D.A specification #15 test is an example of method with no cervical coverage. But, this does not represent the realistic clinical condition. In Group A acrylic was not been extended to cervical collar of the teeth. We found a significant decrease in shear bond strength when the acrylic was not extended up to the cervical collar of the tooth.

Cervical coverage of artificial teeth by denture base material in bond strength tests may be an inconvenience because the study variable (surface treatments and modifications) may suffer the interference of mechanical retention. Nevertheless, it is important to ratify that partial covering of cervical surface of teeth ("neck") is a common practice, and occurs in most of the complete and partial dentures because of technical and esthetic reasons [27].

Effect of surface treatment with Monomer

This study showed that painting ridge lap surface with monomer liquid can result in significant improvement in the shear bond strength. The efficacy of monomer application in improving the bond strength has been cited in previous studies [9]. Monomer application dissolves part of PMMA of the tooth and provides free double bonds that may copolymerize with the PMMA of the denture base resin [28]. However, Vallittu [29] stated that the monomer dissolves the tooth surface and forms a durable secondary semi-interpenetrating polymer networks (IPN) structure. Although the different protocols of monomer application did not significantly affect the bond strengths, in general, the 60 seconds monomer treatment group showed higher bond strength than the 180 seconds treatment group. Using 180 seconds, higher monomer evaporation could have occurred, so less MMA would be available to react with the denture base resin [5].

Effect of sandblasting with Aluminum Oxide powder

Barpal [3], Chung [30] and Saavedra G [8] in their studies compared different surface modifications and found sand blasting better than no surface modification. The results of the present investigation were consistent with the findings of those studies.

This improvement in bond strength can be explained on the basis of the fact that surface roughening with sand blasting increased the surface area available for bonding where some mechanical interlocking might have occurred across the interface [13]. It is also possible that the increased magnitude of bond strength might have occurred due to enhanced surface reactivity as a result of the removal of a saturated surface layer by sand blasting and the exposure of the subsurface layer of a higher free surface energy available for bonding [13]. In fact, the free surface energy of the newly sandblasted resin surface created by sandblasting with Alumina is undoubtedly higher than that of the untreated surface, which may be a reason why roughening improves bonding [31].

Azad Ali [32] in his study found a significant decrease in bond strength after sand blasting. This difference could be explained on the basis of the time of dewaxing. In contrary to our study, where sand blasting was performed after dewaxing, in this study sand blasting was done before dewaxing which lead to residual wax on rough surface that made efficient dewaxing difficult. Contamination with wax has been shown to be the major cause for bond failure between teeth and denture base resins [14,16,33]. Thus, sand blasting, if performed, must be carried out after dewaxing.

Effect of Diatoric recess

This study revealed that mechanical modification with a diatoric recess prepared on ridge lap surface of denture teeth significantly improved the bond strength of denture teeth to the acrylic resin denture base. This coincides with the findings of Takahashi [21], Meng [20], Spratley [14], Cardash [12] and Fletcher [13]. They concluded that preparation of a diatoric recess in the denture tooth resulted in higher bond strengths. Meng [20] concluded that there is 27% increase in bond strength with diatoric recess preparation. The surface topography investigation has shown a combination of micro and macromechanical retention systems in the diatoric recess group that resulted in higher bond strengths. Besides increase in surface area, Takahashi [21] explained this improved bond strength in terms of biomechanical advantage. The diatoric of denture base resin embedded in the denture tooth creates a path of resistance to fracture in a direction different from the denture tooth–denture base resin interface. However, some studies did not find any significant improvement in bond strength with diatoric recess preparation on ridge lap surface. Cardash [15], Vallittu [10] and Buyukyilmaz [34] reported poorer strength of the bond with diatoric recess preparation. This decrease in bond strength was due to improper penetration of acrylic resin into the diatoric recess. They have demonstrated void spaces inside the teeth that had diatoric recess in SEM photomicrographs [10].

Mode of failures

The fractured surface of the sheared specimens was analyzed visually with magnifying loupe (5 x) to determine the modes of failure. Inspection of the fracture surface under visual examination either without aids [16,25,35,37-39] or under magnification with magnifying loupe [40,41], Photomicroscope [20,42] and SEM [12,22,43,44] has been reported in literature. The failure modes were categorized according to the following classification:

1) Adhesive: Facture at occurred at the tooth/denture base interface;

2) Cohesive: Fracture within the acrylic resin or the tooth and

3) Mixed: Significant areas of adhesive and cohesive failures occurred simultaneously.

The failure modes has been classified as adhesive, cohesive and mixed in previous studies [12,16,22,25,35,37,38,39,40-44] Vallittu [22] considered failure to be cohesive if more than 75% of the area of the failure surface was covered with a layer of either tooth acrylic resin or PMMA base material.

In the present study, when fracture interface was evaluated, it was found that mixed failure occurred in most of the specimens. An interesting observation was that the adhesive failure was higher in untreated specimens (Group A and Group B) and such failure decreased with surface treatments and mechanical modifications of ridge lap area. None of the samples with surface treatments showed adhesive failure. 90% of specimens in Group D fractured cohesively within the tooth. The study conducted by Cunningham [16], Meng [56], Vallittu [22], Hilary P. Y. Thean [36] and Mosharraf [37] supported our findings. If debonding does not occur in the tooth denture base interface, the bond can be considered adequately formed and strong [20]. The bond strength of acrylic teeth to denture base seemed more than adequate, after surface treatments and mechanical modifications, because the majority of the fractures in these groups did not occur at the tooth-bond interface. This may suggest that the bond strength in itself was good and that the tooth or the denture base had reduced strength.

It has to be considered that the current experiment was conducted under optimal *in vitro* conditions, which limits the portability of the results to the clinical situation. Nevertheless, standardization of the setup allowed a reliable differentiation between the various surface treatments and modifications of denture teeth, which are valuable to predict their suitability under *in vivo* conditions.

Limitations of the study

1. This study only pertains to *in vitro* shear bond testing. Results of *in vitro* study might not be completely appreciable in clinical practice.
2. The dynamic forces of mastication or fatigue loading and specimen ageing have not been considered.
3. Only single loading point and angle were tested. Anterior teeth contact in a variety of positions and angles which were not tested in this study.
4. Other factors that influence the bond strength between denture teeth and denture base resin, such as different laboratory processing steps have not been considered.
5. The immersion of samples in distilled water may not accurately represent the actual clinical reality.

Conclusion

Within the limitations of this *in vitro* study, it was concluded that surface treatments and mechanical modifications of ridge lap surface of acrylic denture teeth resulted in significant improvement in shear bond strength between acrylic denture teeth and heat cure PMMA denture base resin. The highest bond strength values were observed for specimens treated with sandblasting.

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Volume 6 Issue 6 December 2016