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ORIGINAL RESEARCH

Comparative Evaluation of Bond Strength of Surface-treated and Surface-modified Anterior Acrylic Teeth to Heat Cure Denture Base: An *in vitro* Study

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ABSTRACT

Background: Acrylic resin ruled the dental profession for 60 years, and this success is attributed to its esthetics, handling properties, physical and biological compatibility, stability in oral environment, and cost-effectiveness.

Aims and objectives: The objective of this study was to evaluate and compare the bond strength of acrylic resin teeth treated with various surface treatments and surface modifications like cingulum ledge, sandblasting, and dichloromethane.

Materials and methods: The study was carried out in which 80 samples were grouped into four groups. The groups were: Control group, Cingulum ledge as mechanical surface modification, Sandblasting as micromechanical surface modification, Dichloromethane as chemical surface modification. The samples ware retained in wax pattern with the help of surveyor, then flasked, trimmed, and polished. The prepared samples were then subjected to shear bond strength using the Instron Universal Testing Machine at an angle of 45°.

Results: Creation of cingulum ledge, sandblasting, and/or application of dichloromethane increased the bond strength between acrylic teeth and denture base, when compared with the conventionally processed samples, i.e., control group. However, it was found that application of dichloromethane increased the bond strength more than creating cingulum ledge and sandblasting.

Observation and conclusion: Application of dichloromethane is advised to enhance the bond strength as it is easy for application, increases bond strength compared with creation of cingulum ledge and sandblasting

Keywords: Acrylic resin denture bases, Acrylic teeth, Cingulum ledge, Dichloromethane, Surface treatment, Teeth debonding

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INTRODUCTION

Harold Vernon first introduced acrylic polymers as denture base materials in 1937. A survey showed that 33% of denture repairs were to restore debonded teeth.[1] Factors that affect the bonding of acrylic resin teeth to the denture base are dewaxing procedures, residual wax on ridge laps of teeth,[2] and careless application separating media like sodium alginate to the teeth, leading to contamination of the ridge lap surface.[3] However, attempts to increase the strength of the bond between acrylic resin teeth and heat cured denture base resin include[4,5]:

- Grinding glossy ridge lap surface of resin teeth.
- Painting ridge lap surface of teeth with chemical solutions.
- Cutting retention grooves on ridge lap surface of teeth.
- Use of detergent solution on ridge lap surface of teeth.

The most common tooth to debond is maxillary central incisor.[4] Chung[6] stated creation of micromechanical aids, such as sandblasting, to ridge lap area increases bond strength between acrylic denture teeth and heat cure denture base. Takahashhi et al[7] advocated use of chemical solvents, such as dichloromethane to increase bond strength between acrylic teeth and heat cure denture base.

AIM

To compare the effect of surface modification and surface treatment on anterior acrylic denture tooth for bonding with heat cure denture base resin.

OBJECTIVES

- To evaluate bond strength between heat cure denture base and (1) Control group, (2) Cingulum ledge as mechanical surface modification, (3) Sandblasting as micromechanical surface modification, and (4) Dichloromethane as chemical surface treatment.
- To compare increased bond strength between heat cure denture base and anterior acrylic tooth due to application of (1) Cingulum ledge, (2) Sandblasting, and (3) Dichloromethane.

Table 1: Surface treatments and surface modifications

Groups	*Modifications*
I	Anterior acrylic tooth without any surface treatment and surface modification as control group
II	Anterior acrylic tooth with cingulum ledge as mechanical surface modification
III	Anterior acrylic tooth with sandblasting as on micromechanical surface modification
IV	Anterior acrylic tooth with dichloromethane as chemical surface treatment.

MATERIALS AND METHODS

Sample Size

- A total of 80 samples were fabricated, which were divided into following groups: Anterior acrylic teeth (maxillary right central incisors) from DenTek SP Dental, Pune, India, were used and divided among four groups (n = 20) (Table 1).

Procedure

The ground surface on ridge lap area was sandblasted using an abrasion equipment (mestra T2) with 110 µm aluminum oxide particles (KOROX 110) under 5 kg/cm^2 of pressure with circling motion at 8 mm distance for 5 seconds. Cingulum ledge formation was standardized with a straight hand piece mounted on milling machine and the specimens mounted on platform moving in one direction (Fig. 1) only so that the entire ledge formed is of same dimension and at same location. Depth of ledge was kept 1 mm with the help of flat end straight fissure tungsten carbide bur. First layer of dichloromethane (Fig. 2) was applied with brush followed by application of second layer after 10 minutes for chemical treatment.

A steel split mold (Fig. 3) used for fabrication of wax block measuring 10 × 10 × 25 mm. Each tooth after specific surface treatment was fixed in molten wax poured in steel split mold with the help of surveyor (Fig. 4).

The obtained wax blocks (Fig. 5) along with the teeth were processed (Figs 6 to 8) by conventional curing method as per American Dental Association (ADA) specification no 15 and tagged according to sample group. Shear load was applied at 45° on the center of palatal surface (Fig. 9) of each tooth until separation (fracture or debonding) takes place at a speed of 5 mm/minute.

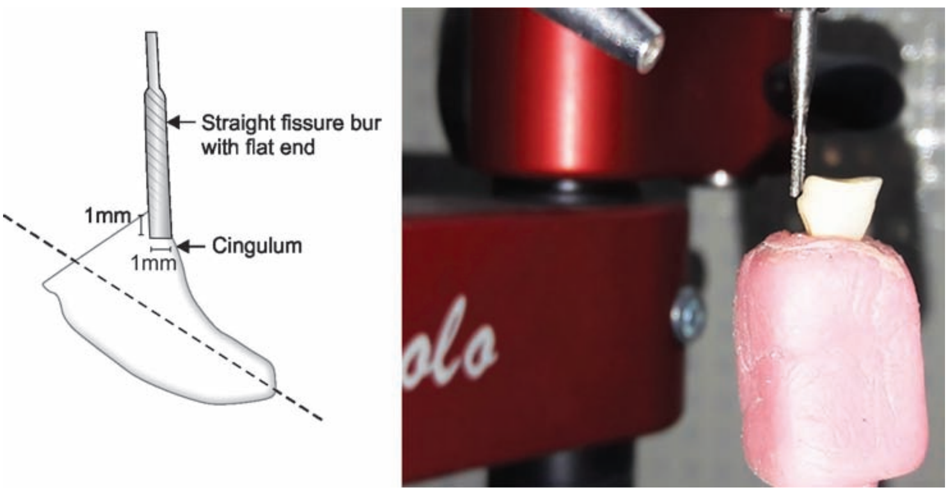


Fig. 1: Cingulum ledge creation

Fig. 2: Chemical solvent – dichloromethane

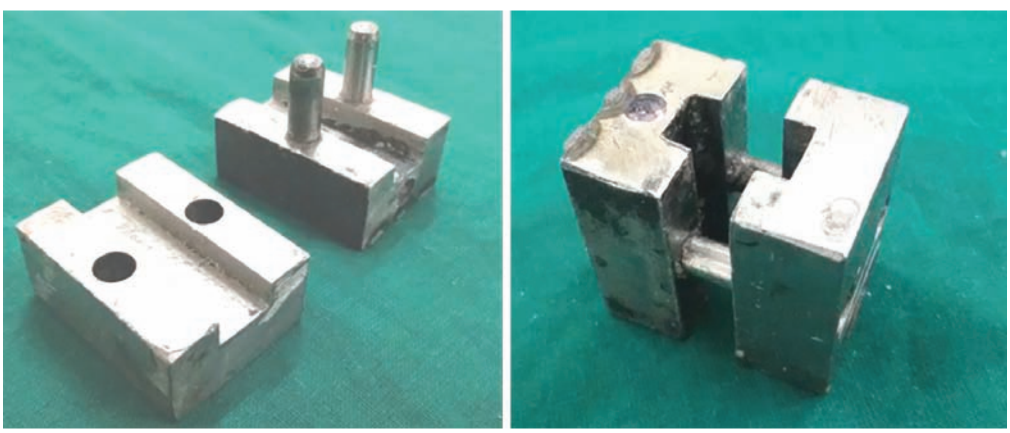


Fig. 3: Stainless steel split mold

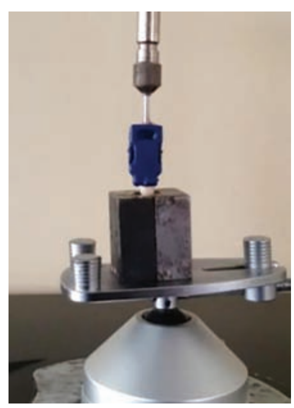


Fig. 4: Securing tooth in wax pattern

Fig. 5: Tooth within wax pattern

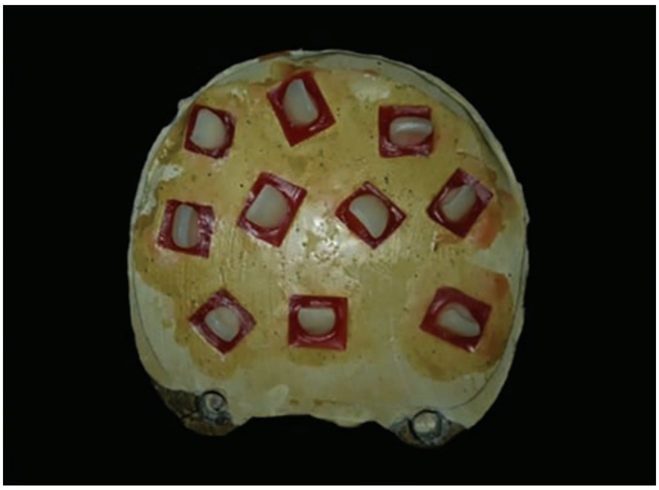


Fig. 6: Flasking

Universal testing machine was used for the evaluation of bond strength between acrylic teeth (four different groups) and denture base. The separation occurring within the tooth, with the acrylic resin base structure or within the acrylic resin with tooth structure along with it, was considered as fracture (Fig. 10). Separation that occurred at the tooth and resin interface without any portion of denture base acrylic on ridge lap area seen with naked eyes was considered as debonding (Fig. 11).

OBSERVATION AND RESULTS

Table 2 gives descriptive statistics for fracture strength of all the four groups with minimum force of 177.33 N and maximum of 483.140 N. The mean force required to fracture or debond the acrylic teeth to heat cure denture base is 322.80 N with standard deviation of 79.89 N.

Graph 1 describes overall frequency distribution for remark in the study showing debonding took place in 19 (23.7%) samples and fracture took place in 61 (76.3%) samples, where sample size was 80. One-way analysis of variance (ANOVA) test used for comparing fracture strength among four groups shows (Table 3) statistically significant ($p < 0.001$) improvement in bond/fracture strength.

DISCUSSION

Several techniques, such as compression molding, injection molding, and materials, such as heat-activated resins, chemically activated resins, light-activated resins are

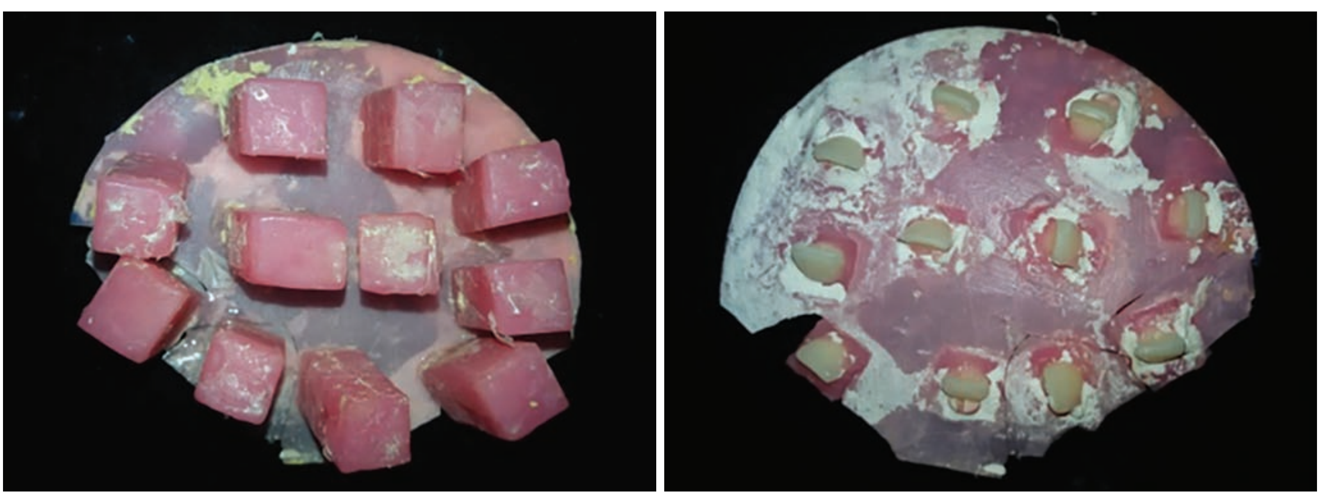


Fig. 7: Deflasking

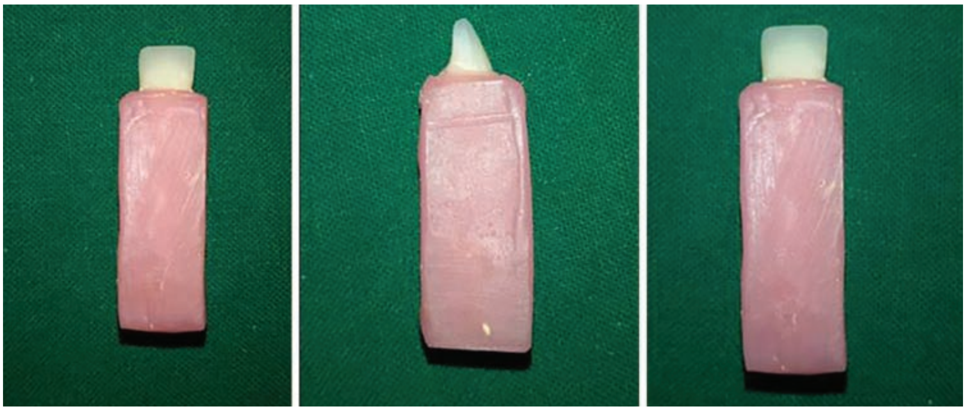


Fig. 8: Finished samples

Fig. 9: Application of shear load on universal testing machine

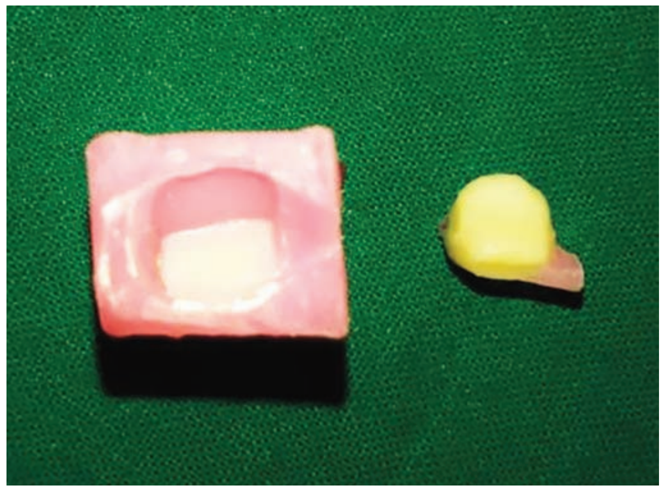


Fig. 10: Fracture

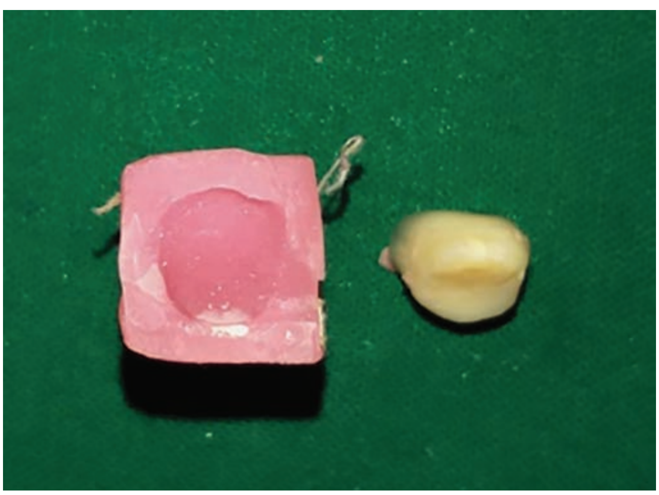
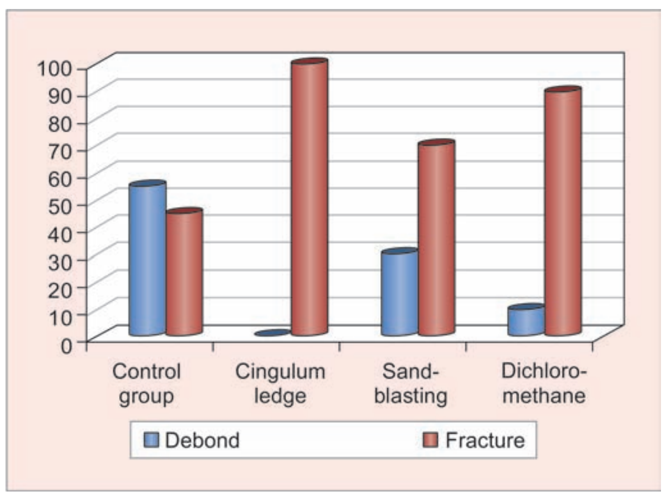


Fig. 11: Debonding



Graph 1: Frequency distribution for remark among four groups

Table 2: Descriptive statistics for overall bond/fracture strength

	Descriptive statistics				
	n	*Minimum*	*Maximum*	*Mean*	*Standard Deviation*
Bond/fracture strength	80	177.380	483.140	322.804	79.89905

Table 3: Comparing fracture strength among four groups by ANOVA

Strength	*Sum of squares*	*df*	*Mean square*	*f-value*	*p-value*
Between groups	186,077.72	3	62,025.909	14.812	< 0.001 HS
Within groups	318,247.17	76	4,187.463		
Total	504,324.90	79			

HS: Highly significant; df: degree of freedom

available for denture fabrication. Acrylic teeth are preferred over porcelain teeth because of its many properties. The main problem faced by laboratory technicians/dentist is frequent adhesive failure between denture base and acrylic tooth. Spratley[8] found that the failures were occurring within the acrylic resin of the tooth close to the junction with the acrylic resin base. Morrow et al[9] in their study found that 70% of the fractures occurred within the tooth.

In case of acrylic teeth, bonding between acrylic teeth and denture bases occurs via chemical bond which depends on the softening of the resin at the base of the teeth with monomer from the "dough" of denture base material. When a denture tooth is fractured away from a sample of a denture base, the fracture path must not occur along the interface between the tooth and denture base, i.e., the fracture must be cohesive.[10]

In the present study, the cingulum ledge was created with dimension of 1 mm deep and 1 mm wide. The strength or weakness of the cingulum ledge lock joint may be influenced by the dimensions and physical properties of the materials from which it is composed. If the ledge is too shallow, the lingual lock may be weak. If the ledge is too deep, the strength of the tooth may be compromised. The internal and external angles of the cingulum ledge should be rounded to avoid areas of stress. The gingival cuff should completely cover the collar of the denture tooth and be as heavy as possible. The denture tooth cannot separate from the denture base until one or more of these parts fractures. The cingulum ledge lock may be an effective form of mechanical retention. In this experiment, the mechanical interlock joined polymethyl methacrylate (PMMA) denture teeth to the denture base with a union that was stronger than the material from which the parts were composed.

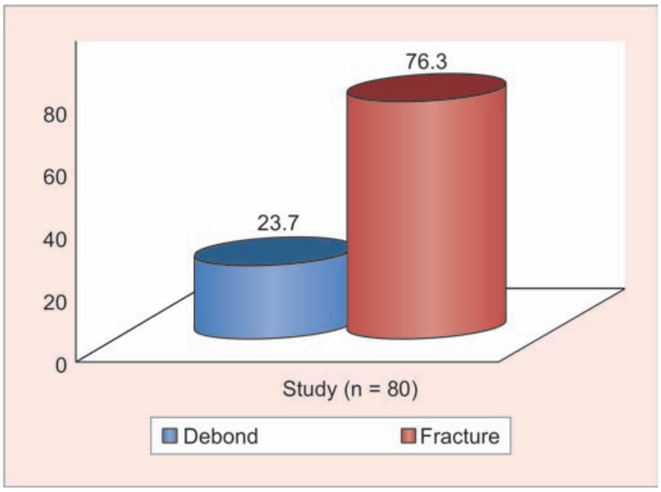
Air abrasion is supposed to increase shear bond strength either by augmenting free surface energy of the newly abraded resin surface or by causing severe irregularities and undercuts in the ridge lap surface area, improving micromechanical retention. In addition, wetting the acrylic resin surface with methyl methacrylate monomer was reported to increase the bond strength between resin polymers. Cohesive failure could also explain as evidence that monomer containing the greater amount of cross-linking agent facilitated the infiltration of polymerizable materials from the denture base into the undercuts and improved the formation of a more extensive interwoven polymer network.[11] Alumina air abrasion is utilized to roughen the repair surface of the denture base to increase the area of bond contributing to micromechanical retention and eliminating substances which adhere to the surface of the repair region, mechanically facilitating application of solvent or PMMA monomer.

Dichloromethane is an organic and nonpolymerizable solvent, which swells the surface and permits a diffusion of the polymerizable material. The strength of the bond depends upon the degree of penetration of the solvent and the strength of the interwoven polymer network formed thereafter.[11] Dichloromethane preparation can create surface pores and channels approximately 1 μm in diameter on a conventional acrylic resin tooth, and these channels tend to interconnect frequently.[7] This morphological change also occurs when dichloromethane is applied to heat processed denture base resin. Prepolymerizing PMMA pearls present in the denture base resin should allow diffusion of the dichloromethane solvent. Vallittu and Ruyter[12] previously described diffusion of MMA solvent into the matrix and interpenetrating polymer network of dental polymer. Since the prepolymerizing PMMA pearls are not cross-linked with the matrix, application of solvent can create cross-linking.

The mean force required to detach acrylic tooth from heat cure denture base is 322.80 N (Table 2), whereas maximum bite force, exerted by complete denture wearers, is commonly low, 90 N, and shows a range of 10 to 210 N.[13] For implant supported over denture, mean bite force is 12.22 ± 27 kgf, i.e., 119.83726 N.[14]

Graph 2 shows debonding for control group that took place in samples. The result indicates that in control group, incidence of debonding and fracture is almost the same. In the group teeth treated with cingulum ledge, all teeth were fractured after application of force. Possible reason for this may be the mechanical interlock joined PMMA denture teeth to the denture base with a union that was stronger than the material from which the parts were composed.

For sandblasting group, debonding of 30% and fracture 70% samples took place. Possible reason for this may be the micromechanical interlock created due to surface



Graph 2: Debonding *vs* fracture of sample

roughness or undercuts joined PMMA denture teeth to the denture base with a union that was stronger than the material from which the parts were composed. For dichloromethane group, debonding of 10% and fracture of 90% samples took place. Possible reason for this may be the application of dichloromethane swells the surface and permits a diffusion of the polymerizable material. The strength of the bond depends upon the degree of penetration of the solvent and the strength of the interwoven polymer network formed thereafter.

In most of the cases, the fracture occurred at the tooth and resin interface. The fractures were occurring within the tooth, along with the acrylic resin base or within the acrylic resin itself along with acrylic tooth. This may suggest bonding between denture teeth to the denture base with a union that was stronger than the material from which the parts were composed.

One-way ANOVA test used for comparing fracture strength among four groups (Table 3) shows statistically significant ($p < 0.001$) improvement in bond strength. Tukey's *post hoc* test was used to do intergroup comparison for strength in Table 4.

This indicates statistically significant increase in bond/fracture strength of surface-treated and surface-modified tooth to heat cure denture base ($p < 0.001$). The difference in fracture strength between sandblasting and cingulum ledge is not significant ($p = 0.538$). Even though the difference in fracture strength between dichloromethane and cingulum ledge ($p = 0.061$) and the difference in fracture strength between dichloromethane and sandblasting ($p = 0.069$) is not statically significant, the p value is near to 0.05, which indicates dichloromethane increases the bond/fracture strength than other surface treatments.

Table 5 comparing remark level (debond/fracture) among four groups by Kruskal–Wallis test shows

Table 4: Comparing fracture strength within four groups (one to one comparison) by Tukey's *post hoc* test

Multiple comparisons

Dependent variable: Strength Tukey's HSD

(I) Group	*(J) Group*	*Mean difference (I - J)*	*Standard error*	*Significance*	*95% Confidence interval*	
					Lower bound	*Upper bound*
Control group	Cingulum ledge	–77.1120*	20.46329	<0.05 S	–130.86491	–23.35909
Control group	Sandblasting	–104.611*	20.46329	<0.001 HS	–158.36391	–50.85809
Control group	Dichloromethane	–128.121*	20.46329	<0.001 HS	–181.87391	–74.36809
Cingulum ledge	Sandblasting	–27.49900	20.46329	0.538 (>0.05 NS)	–81.25191	26.25391
Cingulum ledge	Dichloromethane	–51.00900	20.46329	0.061 (>0.05 NS)	–104.76191	2.74391
Sandblasting	Dichloromethane	–43.51000	20.46329	0.069 (>0.05 NS)	–97.26291	13.24291

*The mean difference is significant at the 0.05 level; HSD: Honest significant difference; S: Significant; HS: Highly significant; NS: Not significant; The Tukey's *post hoc* test used to do intergroup comparison for strength

Table 5: Comparing remark level among four groups by Kruskal–Wallis test

Ranks

	Group	*n*	*Mean rank*
Remark	Control group	20	28.00
	Cingulum ledge	20	50.00
	Sandblasting	20	38.00
	Dichloromethane	20	46.00
	Total	80	
Test statistics[a,b]		*Remark*	
Chi-square		19.290	
df		3	
Asymp. sig. p-value		<0.001	

Statistically significant; p value – repeated measures ANOVA test; Pairwise sig; Tukey's *post hoc* test; Significant (S): $p < 0.05, < 0.01$; HS: Highly significant: $p < 0.001$; NS: Non significant; $p > 0.05$; a. Kruskal–Wallis test; b. Grouping variable: Group

Table 6: Groupwise frequency distribution for remark in the study

Group	*Remark*	*Frequency*	*Percent*	*Valid percent*	*Cumulative percent*
Control group	Debond	11	55.0	55.0	55.0
	Fracture	9	45.0	45.0	100.0
	Total	20	100.0	100.0	
Cingulum ledge	Fracture	20	100.0	100.0	100.0
Sandblasting	Debond	6	30.0	30.0	30.0
	Fracture	14	70.0	70.0	100.0
	Total	20	100.0	100.0	
Dichloromethane	Debond	2	10.0	10.0	10.0
	Fracture	18	90.0	90.0	100.0
	Total	20	100.0	100.0	

statistically significant value of $p<0.001$ [chi-square $>= 19.290$; degrees of freedom (df) = 3]. This indicates the difference between fractures and debonding is statistically significant. Table 6 shows groupwise frequency distribution for remark level (Debond/fracture)

Maximum bite force, exerted by complete denture wearers, is commonly low (90 N) and shows a range of 10 to 410 N.[13] However, it should be emphasized that 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. Another interesting consideration is that the tooth displacement from the complete denture may only occur due to mechanical fatigue from repeated chewing, accidental falling, or by incorrect laboratory technique.[15]

This study hypothesized that surface treatment/surface modifications would provide more retention against dislodgement of the denture tooth from the denture base. This hypothesis was accepted, as the results demonstrated that the control surface obtained lowers bond strength values than the surface treatment/modification groups. The group treated with dichloromethane showed higher bond/fracture strength followed by sandblasted and cingulum ledge group.

Within the limitations of this study design and without consideration human chewing patterns and intraoral conditions, specimens in this *in vitro* study were prepared and loaded to simulate clinical conditions according to the American National Standards Institute/ADA specification no. 15.

CONCLUSION

Within the limitations of this study, following conclusions can be drawn:

- Surface treatment or surface modification significantly improved the bond strength between acrylic teeth and the denture base resins as compared with conventionally processed samples, i.e., control group.
- Dichloromethane improves bond strength more than sandblasting and cingulum ledge. Hence, application of dichloromethane is advised to enhance the bond strength as it is easy for application, increases bond strength as compared with creation of cingulum ledge and sandblasting.
- The failure mode after surface treatment or surface modification was predominantly cohesive, i.e., fracture as compared with debonding.

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