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The Acrylic Tooth-denture Base Bond: Effect of Mechanical Preparation and Surface Treatment

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Abstract - *The bond strength of acrylic teeth to denture base resins was tested using a widely-accepted technique. The pre-treatments included abrading and grooving the teeth, the application of monomer and the application of a proprietary bonding agent. Each of the 360 specimens was tensile-tested until fracture, using a universal testing machine. When bonded to heat-cured resin, the grooved teeth had the highest mean bond strength while the grooved monomer-treated group had the lowest. When bonded to cold cure resin, the unabraded monomer-treated teeth had the highest mean bond strength and the unabraded group the lowest.*

KEY WORDS: Denture teeth, acrylic resin bonding, auto-polymerising acrylic resin

INTRODUCTION

Acrylic resin denture teeth are widely used in prosthetic dentistry, principally because of the ability to bond chemically to denture base resin. These teeth are usually manufactured by compression moulding, or transfer moulding, and adhere to European standard EN ISO 3336:1996. However, despite high standards of manufacture, there is still a problem with denture teeth sometimes de-bonding from the denture base resin. A survey of dental laboratories published in 1994 found that 33% of repairs carried out were due to de-bonding or fracture of denture teeth[1]. Various methods of preparing the teeth are used by dental laboratories to reduce the risk of de-bonding, including roughening and/or grooving the ridge lap area of the teeth, the application of monomer to the teeth before packing and the use of proprietary bond enhancers.

Chemical bonding between the teeth and the polymer/monomer dough occurs through the absorption of monomer by the surface layers of the teeth. Monomer is exposed on the surface of the dough due to the pressure exerted when closing the processing flask. This monomer is subsequently co-polymerised with the denture base to form inter-penetrating polymer networks which may be covalently inter-connected by chain transfer reactions.

There is conflicting evidence in the literature as to the benefit of mechanical preparation of the teeth, with some authors finding no benefit[2, 3, 4, 5, 6] and others finding that there is some advantage[7, 8, 9, 10]. There is also conflicting evidence regarding the benefit of monomer application to the teeth, as the effect seems to depend on the brand of tooth and denture base resin[6, 11]. A proprietary bonding agent, Vitacoll[TMa] , has been found to be effective with some brands of denture base resin but not with others[6, 12]. Chung et al (1995)[9] reported that roughening the ridge lap surfaces of acrylic denture teeth and pre-wetting with monomer-solvent mix increased the bond strength between teeth and cold-cure denture base resins. They did not test for the same effect in heat-cure resins.

There are a variety of methods of preparing specimens and testing bond strength, designed to comply with various national standards (e.g. ISO 3336, 1993; ANSI/ADA 15, 1985). This may be part of the reason for the sometimes conflicting results. The method of Cunningham and Benington (1996)[5] was chosen for this investigation for the following reasons:

- Specimens are not machined after processing and therefore additional stresses are not induced.
- Bonding with the occlusal (or incisal) surface of the specimen is not required
- It is practical to produce large numbers of specimens and this permits adequate sample sizes.

The aim of this investigation was to determine the bond strength between a particular brand of denture teeth and one brand of auto-polymerizing resin and one brand of heat-curing resin, using different methods of preparation of the ridge lap area of the teeth. The preparation consisted of roughening of the ridge lap area, cutting a horizontal groove and the use of a monomer or proprietary bonding agent. These preparations were done either singly or in combination.

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MATERIALS AND METHOD

The teeth used in this study were cross-linked acrylic resin central incisors (Senator)[b]. These teeth are manufactured by compression moulding and the ridge lap surface has 6% cross linkage. In total, 360 teeth were used (180 bonded to heat-cure acrylic and 180 bonded to cold-cure). Each tooth was prepared in one of 6 different ways:

1. Unabraded tooth i.e. no preparation
2. The application of monomer to an unabraded tooth for 5 minutes prior to packing.
3. The application of a bonding agent (Vitacoll) to an unabraded tooth.
4. The preparation of a horizontal groove
5. The preparation of a horizontal groove and the application of monomer
6. The preparation of a groove and application of Vitacoll

Each tooth was bonded to either an autopolymerizing resin (hereafter referred to as "cold-cure") (Palapress)[c] or a heat-curing resin (hereafter referred to as "heat-cure") (Trevalon)[d]. Thirty tests were carried out on each tooth-resin combination, making a total of 360 tensile tests.

The preparation of the specimens for the bonding tests was done using a previously published method[5]. To prepare a pattern for the specimen, each tooth was bonded to a PTFE collar using cyanoacrylate cement. The collars were specially manufactured for this project. A pre-formed brass tensile pattern (TN 1135)[e] , with one end removed, was inserted into the tooth-collar assembly (Figure 1). These patterns, consisting of the tooth with PTFE collar and brass tensile pattern, were embedded to half their depth in heavy body polyvinylsiloxane impression material within specially made trays. The trays were placed in dental stone within standard dental flasks. The impression material was carefully trimmed, separating medium applied and the second half of the flasks was poured.

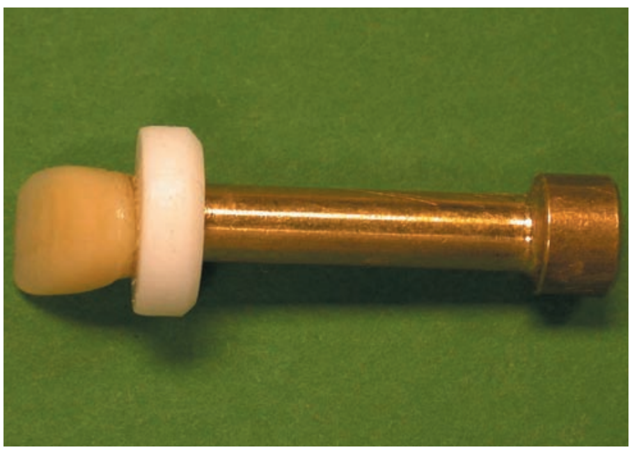

Figure 1. *The brass pattern is attached to the tooth and PTFE collar prior to investment to create a mould for the manufacture of specimens. When the mould is produced, the tooth and collar is bonded to acrylic to create a specimen which is then available for tensile testing.*

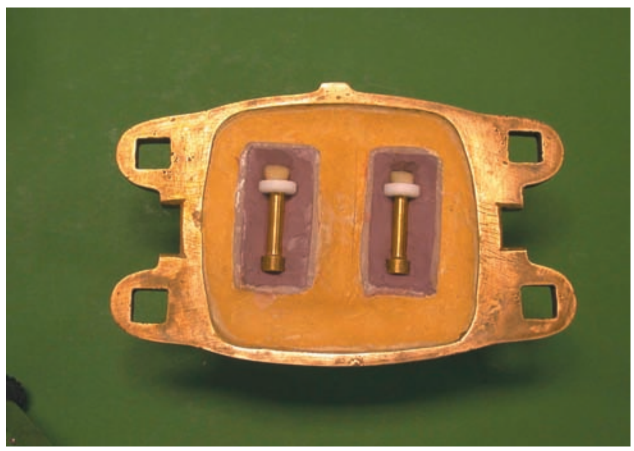

Figure 2. *One half of the flask containing the tooth, PTFE collar and brass pattern. These may now be removed, tooth and collar replaced and the mould packed with acrylic resin.*

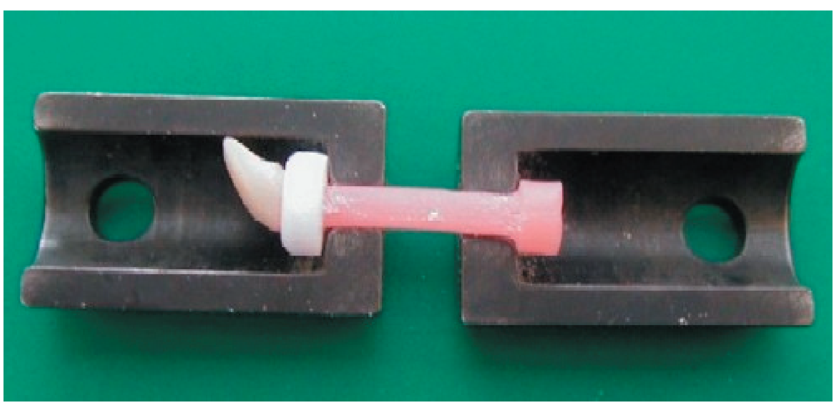

Figure 3. *A processed specimen (tooth and PTFE collar bonded to acrylic resin) placed in one half of the two chucks ready for tensile testing.*

After these moulds were created, the brass tensile patterns were removed. Teeth were replaced into the mould with a new PTFE collar which had a hole reamed to a taper of 1 in 50, the smaller side against the tooth, to provide a standard contact area for acrylic to tooth ridge lap. In this way, each tooth had the same contact area with acrylic and there was a clear path for the flow of acrylic and bonding with the tooth was unimpeded by the collar. Specimens were then created by pouring either cold-cure or heat-cure resin into the mould containing teeth and PTFE collars (Figure 2). After a specimen was cured, it was carefully removed from the mould. The moulds were then re-used, but freshly-prepared teeth with new collars were inserted into the moulds before loading with the appropriate acrylic resin. In order to minimise acrylic flash, the PTFE collars were manufactured with a 10 degree taper at the face in contact with the tooth and a relatively flat mould of tooth was chosen. The small amount of flash that did occur was removed carefully under magnification with a tungsten carbide bur.

After curing and the removal of any acrylic flash, each specimen was placed in the chucks of a universal testing machine [f]. The manner in which a tensile load was applied to each specimen may be seen in Figure 3. The specimens were strained at a crosshead speed of 2.5 mm/min until fracture occurred. The site of fracture was visually inspected to determine the type of failure; cohesive failure was considered to have occurred when acrylic resin was still attached to the tooth and adhesive failure was considered when no acrylic was present on the tooth surface at the site of failure.

Statistical Analysis

A generalised linear model procedure was used to examine for the effects of tooth preparation and for type of acrylic resin denture base material, together with the interaction between these two factors. Follow-up multiple comparisons (Bonferonni adjusted) were carried out as necessary to test for differences between groups.

RESULTS

The general linear model procedure (Table 1) showed a significant interaction between resin type and treatment ($p<0.001$). The effect of treatment was also significant ($p<0.019$). The means and standard deviations of the bond strengths for the 6 different treatments, when bonded to heat-cure or to cold-cure resin, may be seen in Figure 4 and Table 2. For the heat-cure groups, the grooved monomer-treated teeth (GRM) had the lowest mean bond strength (0.462 ± 0.098 kN), while the grooved teeth (GR) had the highest mean bond strength (0.599 ± 0.124 kN). The three highest groups were the unabraded bonding-agent treated (UNB), unabraded (UNA), and grooved (GR), in the order of lowest to highest. However, there was no significant difference between the grooved teeth and the unabraded teeth ($P = 0.816$), or between the unabraded teeth and the unabraded teeth which had been treated with bonding agent ($P = 0.738$). The lowest groups were the grooved monomer treated (GRM) and grooved bonding agent (GRB); there was no significant difference between them ($P = 0.423$). When comparing the extremes of mean bond strength, however, there was a significant

Table 1. *General linear model procedure; analysis of variance, using adjusted SS for Tests.*

Source	*DF*	*Adjusted MS*	*F*	*P*
Resin type	1	0.03969	3.46	0.064
Treatment	5	0.03158	2.75	0.019
Resin type/Treatment	5	0.18065	15.75	0.000
Error	344	0.01147		
Total	355			

Table 2. *Mean bond strength (kN) for each acrylic resin and treatment type.*

Resin type	*Treatment group*	*Mean (n = 30)*	*Standard deviation*
Cold cure	Un-abraded	0.4052	0.1275
Cold cure	Un-abraded with monomer	0.5716	0.1098
Cold cure	Un-abraded with bonding agent	0.5170	0.1442
Cold cure	Grooved	0.5050	0.1042
Cold cure	Grooved, with monomer	0.5580	0.0764
Cold cure	Grooved, with bonding agent	0.5571	0.0859
Heat cure	Un-abraded	0.5917	0.1039
Heat cure	Un-abraded, with monomer	0.5247	0.0843
Heat cure	Un-abraded, with bonding agent	0.5822	0.1146
Heat cure	Grooved	0.5986	0.1238
Heat cure	Grooved, with monomer	0.4617	0.0979
Heat cure	Grooved, with bonding agent	0.4819	0.0958

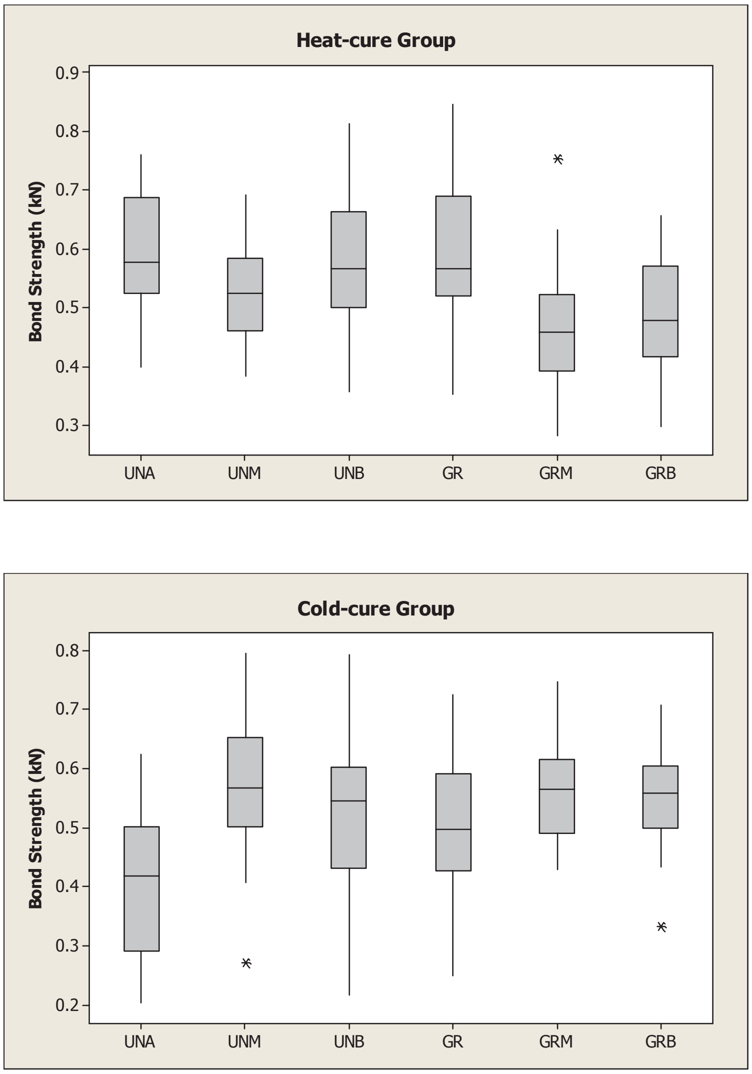

Figure 4. *The means and standard deviations of the bond strengths (kN) for the 6 different treatments, when bonded to heat-cure or to cold-cure resin. Outliers are marked * UNA = unabraded, UNM = unabraded, with monomer, UNB = unabraded with bonding agent, GR = grooved, GRM = grooved with monomer, GRB = grooved with bonding agent.*

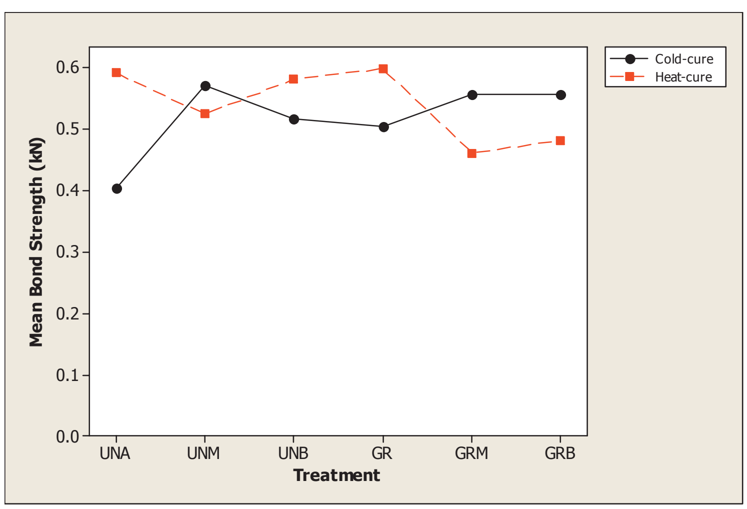

Figure 5. *Interaction Plot – mean bond strength (kN) for various treatments, with heat-cure acrylic resin (dotted line) and cold-cure acrylic resin (solid line). UNA = unabraded, UNM = unabraded, with monomer, UNB = unabraded with bonding agent, GR = grooved, GRM = grooved with monomer, GRB = grooved with bonding agent.*

difference between the lowest and the highest ($P < 0.000$). The unabraded monomer-treated group (UNM) was not significantly different from any of the other treatment groups ($P > 0.05$).

With the cold-cure groups, the mean bond strength of the unabraded group was the lowest (0.405 ± 0.128 kN), while the highest was the unabraded monomer group (0.572 ± 0.110 kN). In between were the grooved, unabraded bonding-agent treated, grooved bonding agent and grooved monomer-treated groups in the order of lowest to highest. There was a significant difference between the unabraded teeth and those treated with monomer ($P < 0.000$).

It may be seen that there are different patterns across the treatments for the heat-cure and cold-cure groups (Figure 5). The patterns are not parallel to each other but rather they seem to be opposing. Regarding the type of failure, in the cold-cure group there were 33 adhesive failures and 147 cohesive failures. In the heat-cure group there were 2 adhesive failures and 178 cohesive failures (Table 3).

DISCUSSION

Different types of mechanical preparation have long been used when bonding acrylic resin denture teeth to acrylic resin denture base materials but various investigators have reported conflicting results on the effect of this preparation on the bond strength. The results from this present investigation show that the preparation of grooves improved the bond strength to both heat-cured and cold-cure resin but this effect was not statistically significant. This improvement in bond strength to both types of denture base resin is likely to be due to the increased tooth surface area available for bonding. It has also been reported by previous authors[2, 8, 9, 10, 13, 14, 15 16] that mechanical preparation of the ridge lap surface of acrylic denture teeth by grinding, placement of grooves, or roughening of the surface increased the bond strength of the tooth-resin bond.

Fletcher et al[7] attempted to explain why roughening the surface should improve the bond strength, by speculating that the surface of the unprepared ridge lap was smooth and relatively un-rutted and therefore offered better wettability. They suggested that the free surface energy of newly exposed acrylic was different from that of the unprepared acrylic and this was why roughening the surface improved the bond. However, others have reported that mechanical preparation did not have an effect on the tooth-resin bond strength[2, 3, 5, 6, 16, 17]. Huggett et al (1982)[2] reported that one brand of acrylic teeth benefited from mechanical preparation when bonded to a cold-cure denture base resin but not to heat-cured resins.

It is important to note that different mechanical preparations, tooth types, acrylic resin denture base types and different testing methods were used in different studies and this could account for the different results obtained. Also, many studies did not compare the effect the same type of mechanical tooth preparation had on the tooth–resin bond using both heat-cure and cold-cure denture base resins.

The use of solvents, monomers and adhesives has revealed conflicting results in the literature. Some have reported that the use of solvents (including monomer) improved bond strengths[18, 19, 20, 21] while others have said that solvents had no effect on the bond strength[2, 14, 22, 23, 24, 25].

Results from this present study showed that for the heat-cure group, the use of bonding agent and monomer on unabraded teeth had no effect on the bond strength when compared to the other heat-cure groups. Even though there was a significant difference between the unabraded bonding-agent treated group and the groups with the lowest mean strengths, there was no significant difference when compared to the unabraded group (which had higher mean bond strength). The unabraded monomer-treated group was in between and was not significantly different from the groups with the lower bond strengths. Therefore it seems that the placement of a groove, with no other treatment, gives the highest bond strength with heat-cure resin.

With the cold-cure group, all of the treatments resulted in an improvement in bond strength over unabraded teeth. The unabraded monomer-treated group had the highest mean bond strength. This difference in the effects of treatments compared to bonding with heat-cure resins could possibly be explained by the fact that cold-cure resins are more heavily plasticized than the heat-cure resins and thus absorb more monomer. The quantity of inhibitor present in the different monomers may not be the same and this may have an affect on the uptake of excess monomer before polymerization is completed.

Table 3. *Summary of types of failures.*

Resin type	*Treatment group*	*No. of adhesive failures*	*No. of cohesive failures*
Cold cure	Unabraded	15	15
Cold cure	Un-abraded, monomer treated	7	23
Cold cure	Un-abraded, with bonding agent	11	19
Cold cure	Grooved	0	30
Cold cure	Grooved monomer treated	0	30
Cold cure	Grooved, with bonding agent	0	30
Heat cure	Un-abraded	2	28
Heat cure	Un-abraded monomer treated	0	30
Heat cure	Un-abraded, with bonding agent	0	30
Heat cure	Grooved	0	30
Heat cure	Grooved monomer treated	0	30
Heat cure	Grooved, with bonding agent	0	30

Barpal et al[11] reported in 1998 that wetting the ridge lap surfaces of teeth with monomer for 30 seconds slightly improved the bond strength to one type of high impact heat-cure base resin (Lucitone 199®). The same treatment decreased the bond strength with another type of high impact heat-cure resin (SR-Ivocap®). They concluded that the bonding of heat-cured high impact acrylic resin to cross-linked teeth can be affected by ridge lap modifications.

There was an increased and significant difference in the mean bond strengths in the cold-cure group when the grooved monomer-treated and grooved bonding agent-treated groups were compared to the unabraded and grooved groups. There was no significant difference, however, between the grooved monomer-treated and grooved bonding agent treated groups. The opposite was the case for the heat-cure group, where the two groups had the lowest bond strengths and were significantly lower than the other groups but not significantly different from each other. This result could possibly be explained by the polymerization time; the heat-cure resin has a longer time to polymerize and the monomer content of the resin is sufficient to diffuse or swell into the polymer powder and so did not absorb the extra monomer or bonding agent applied, while the autopolymerizing resin absorbed the extra monomer or bonding agent. The increase in surface area provided by the grooves also aided in better diffusion of the monomer content of the acrylic resin.

Cunningham and Benington[6] reported in 1999 that coating teeth surfaces with the monomer of Trevalon® (which was also used in this study) increased the bond between the teeth and the resin, while the monomer of RapidRepair® failed to increase the bond strength. However the use of Vitacoll® made a significant improvement to the bond with Trevalon® resin. No change was observed with Redilon® resin. This suggests that the chemical composition of the teeth, denture base resin and solvent used may affect the bond to varying degrees. However, there were some limitations to the technique. Firstly, the development of a flash of acrylic resin between the tooth and PTFE collar could have affected the results. Cunningham and Benington (1996)[5] recognized this problem but they found that the interference was insignificant in terms of the average tooth bonding force. Secondly, tensile forces used to test the specimens do not fully simulate the clinical situation in the mouth where the denture is subjected to a variety of forces over a period of time.

The comparison of the results from this study to other studies is difficult as other methods and different sample preparations were used. Different formulations of products were also used. This could explain the conflicting results found in different studies with regard to the effect of mechanical preparation and ridge lap treatment on the tooth-denture base bond. It would be an advantage to have a universal specimen preparation and testing method to enable different investigations to be directly compared.

CONCLUSIONS

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

- For acrylic resin teeth bonded to heat cure resin, there is no significant benefit in placing grooves, treating with monomer or treating with bonding agent.
- Treating the tooth ridge lap surface with acrylic resin monomer or bonding agent significantly improved the bond strength to cold cure resin.
- The combination of mechanical preparation and monomer or bonding agent treatment did not improve the bond strength to heat cure resin but did so with cold cure resins.
- For the cold cure resin, all the treatment methods improved the bond strength compared to unabraded, untreated teeth.

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MANUFACTURERS DETAILS

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