Bonding of acrylic denture teeth to resin denture bases

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ABSTRACT

Anterior teeth debonding from dentures is a common problem. This study tested the bond strength of denture teeth to two types of denture resin, with and without grooving the ridge-lap surface.

Bond strength and fracture type of three different groups were compared:

1. Teeth bonded to heat-cured polymethyl methacrylate (PMMA);
2. Teeth bonded to pour-type PMMA;
3. Grooved teeth bonded to pour-type PMMA. Specimens were manufactured following ISO standard 22112.

Force values at failure were analysed using one-way analysis of variance, using the mixed procedure with confidence interval of 95%. Types of failure were identified as adhesive, cohesive or combination.

In descending order, mean failure forces were 418.55N (Group One), 367.55N (Group Two) and 290.05N (Group Three). There was no significant difference between the means of groups 1 and 2 ($p=0.0627$). Group Three differed from both other groups ($p<0.001$). Groups One and Two showed predominantly cohesive fractures within denture teeth (83% and 72% respectively); group Three showed predominantly cohesive fractures within the denture PMMA (75%).

Without ridge-lap modification, the bond strengths of denture teeth to pour-type and heat-cured denture resin were similar. Failures were predominantly of cohesive nature within the teeth themselves. Grooving the ridge-lap reduced fracture resistance and led to breakages predominantly in denture PMMA.

INTRODUCTION

One of the reasons why acrylic denture teeth are preferred over porcelain denture teeth is their potential to chemically bond to the denture base. Even so, debonding of acrylic denture teeth from denture bases is a common clinical problem, especially in the anterior region.[1] A survey among British dental laboratories showed that more repairs were necessary due to debonded teeth than to midline fractures.[2]

With the use of implant-supported prostheses, higher impact forces and accelerated fatigue of opposing dentures may be expected. Even in the era of CAD technology, traditional denture base resins and denture teeth are still popular choices for making implant-supported and -retained prostheses.[3] Delamination of denture teeth is a frequent complication for these implant-supported dentures.[3,4] The thickness of the acrylic denture base over the implant attachment systems is also reduced, increasing the risk for fractures. Repairing these implant-prostheses inconveniences the patient and challenges the dental practitioner and technician.

Standards for determining bond strength

Published research on the bond strengths of denture teeth to denture base material is inconsistent with regard to the methodology adopted. Many researchers designed their own approaches, but often failed to simulate the clinical situation. Sometimes, posterior teeth are used, although debonding predominantly affects anterior teeth. Few studies base their methodology on recognised, published standards dealing with testing the bonding of denture teeth, such as the seven listed by Patil *et al.* (2006): the ANSI/ADA 15 (1985), AS 1626 (1974), ISO 3336 (1977), BS 3990 (1980), SABS 1342 (1982), DIN 13914 (1983) and the JIST6506 (1989).[5] Of these, the ISO, BS and SABS are identical. The remaining four standards all differ in their methodology of specimen fabrication, type of load, cross-head speed and minimum acceptable bond strengths.

Extrapolations from laboratory studies

In vitro simulations do not have the same strength of evidence as clinical trials.[6] Denture bases and denture teeth are classified as Class D material.[6] This means that structures made from these materials are subjected to complex function intra-orally, for protracted times. This decreases the likelihood that *in vitro* results correlate well with clinical performance. Therefore, comparisons between laboratory studies and the formulation of clinical recommendations remain tenuous and challenging.

The effect of mechanical and chemical conditions on bond strength

Research on bond strength between denture base and denture teeth focuses mainly on methods of improving the bond of the ridge-lap surface by chemical and mechanical

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conditioning of the denture tooth. Conflicting results have been reported. A popular method is to wipe the ridge-lap surface of the teeth with monomer. A number of publications reported an improvement in bond strength after the application of monomer to the denture teeth,[7-13] while other authors did not identify any such benefit.[14-16]

Ridge-lap modification by grinding and polishing or by grooving also resulted in conflicting reports. Some found no improvement after modification,[9-18] whilst Vallittu (1995) reported that grooving did result in improved bond strength.[19] Different types of grooves did not show any special advantage in bonding.[20] Takahashi *et al.* (2000) found that bond strength was increased when the tooth glaze was intact, without diatoric.[11] Others confirmed that diatoric had no effect on bond strength compared with no treatment.[13-16]

Wax contamination of the ridge-lap surface of denture teeth reduced the bond strength.[9,15] Traces of wax may still be found on denture teeth even after rinsing with water at 90°C.[21] Some say that contamination of the ridge-lap surface with separating medium may also reduce bond strength,[14,22] while others found that it did not do so.[15]

The effect of different resin bases and denture teeth on bond strength

Studies examining the effect of different types of resin bases and polymerisation methods on the bond strength to denture teeth, also reported conflicting results.[7,11,12,23,24] Bonding of denture teeth to high impact resin was better than to conventional resin.[9,14] Visible light-cured resin had lower bond strength to denture teeth compared with heat-cured resin.[11,14,25,26] Vallittu *et al.* (1997) explain that, with an increase in the polymerisation temperature, monomer diffuses more effectively into acrylic teeth, thus increasing the bond strength.[27] However, Fletcher-Stark (2011) found better bonding with light-polymerised urethane dimethacrylate resin compared with heat-polymerised polymethyl methacrylate (PMMA) resin when using a highly cross-linked denture tooth.[13]

There are also disparate results when microwave- and conventional warm water bath-curing methods are compared, with some finding that microwaving produced stronger bonds with denture teeth,[7] some reported weaker bonds[23,28] and some no difference in the bond strengths.[17] Takahashi *et al.* (2000) experienced better bonding for heat-cured and microwave-cured resin when compared with pour-type resin.[11]

Acrylic denture teeth are often made of conventional PMMA resin, but can be partially cross-linked or highly cross-linked, with or without fillers. Suzuki *et al.* (1990) found that the harder the tooth, the weaker the bond to the acrylic resin base.[29] 'IPN'- teeth (interpenetrating polymer network) have lower bond strength to heat-cured resin than do regular acrylic denture teeth.[14]

Takahashi *et al.* (2000) found that conventional resin teeth bonded better than (highly) cross-linked teeth.[11] Chai *et al.* (2000) also looked at the bond strength of conventional resin teeth and highly cross-linked teeth to a pour-type resin.[30] They found no significant differences.

The bonding of artificial tooth resin to denture base acrylic resin has been related to the ability of monomer to diffuse into the tooth resin, observed by the presence of swelling.[27] The degree of swelling is related to the degree of cross-linking of a polymer. If a polymer is highly cross-linked, it has difficulty swelling in organic solvent.

Patil *et al.* (2006), reviewing the literature, found that hydration did not influence bond strengths, while others found that it reduced bond strengths.[3,5] Thermocycling also produced conflicting results. Some found that it reduced the bond strength.[5,30,31,32] Others did not find a difference.[17,33] Marra *et al.* (2009) found that thermocycling actually increased bond for some tooth-resin combinations and decreased it for others.[34] Cyclic loading did not influence bond strength significantly.[13]

Pour-type acrylic resins for dentures have several advantages over heat-cured denture resins. Flasking and deflasking is easier and there is no need for pressure packing or heat-polymerisation. Suppliers of a pour-type denture resin even claim superior bonding between denture teeth and denture base compared with the conventional pressed and heat-polymerised resins. However, at the same time a custom drill is supplied to groove the ridge-lap surface of the denture teeth, supposedly to increase retention and bond. This, together with previously reported weaker bonds for a pour-type resin than microwave or heat-cured resins,[11] prompted the need to investigate the efficacy of the bonding of denture teeth to a pour-type denture resin.

The purpose of this study was to investigate whether there is a better bond between denture teeth and denture base using a pour-type acrylic resin compared with a conventional, heat-polymerised denture base material when using an internationally accepted manufacturing standard.

The null-hypotheses of this study were:

1. There is no difference in resin-tooth bond strength using a pour-type denture base material and a conventional heat-polymerised resin.
2. There is no difference in resin-tooth bond strength between prepared ridge lap tooth surfaces and unprepared ridge lap surfaces.
3. The type of bond failure (adhesive or cohesive) does not differ among the three groups.

METHODS AND MATERIALS

This *in vitro* research project was approved by the Senate Research and Ethical Committee of the University of the Western Cape. The researchers declare no conflict of interest.

Identical central anterior denture teeth (Dentron, Dentsply Intl, York, Pennsylvania, USA) were bonded to a pour-type (Castavaria, Vertex-Dental, Zeist, The Netherlands) or heat-cured (Vertex Rapid, Vertex-Dental) PMMA denture resin. The test groups were as follows:

Group One (control): heat-polymerised acrylic resin, no tooth modification (n=30).
Group Two: pour-type acrylic resin, no tooth modification (n=30).
Group Three pour type acrylic resin, ridge lap surface of teeth grooved (n=40).

Materials were handled according to manufacturers' instructions. Preparation of the specimens and testing of the bond was done according to the ISO 22112 (2005) standard.[35]

The pour-type resin specimens were manufactured using a mould manufactured from rubber impression material (President Impression Putty; Coltene/Whaledent AG, Altstatten

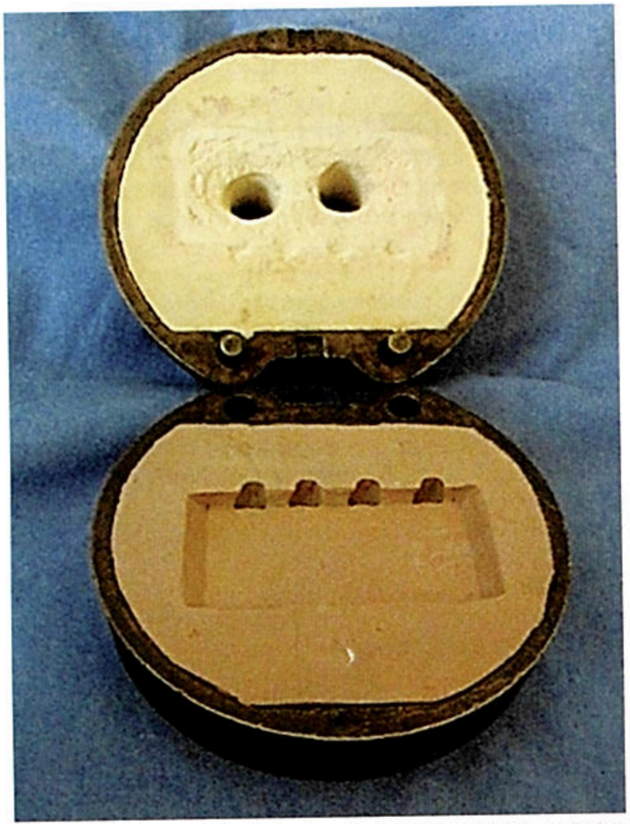

Figure 1: The rubber mould inside the brass flask: the cover of the mould displays the pour holes.

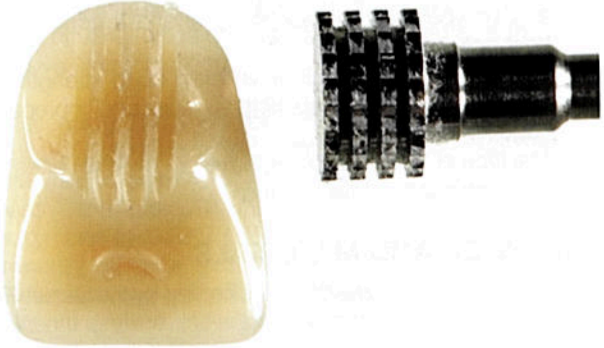

Figure 2: The ridge-lap surface of a denture tooth grooved using the bur provided.
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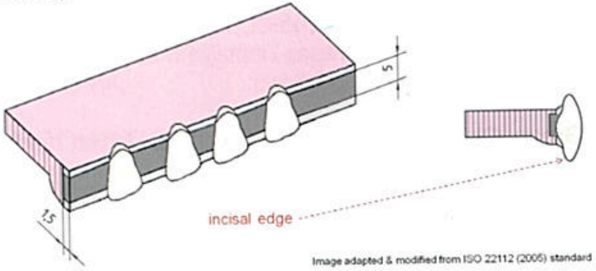

Image adapted & modified from ISO 22112 (2005) standard

Figure 3: Four identical teeth on replica mount before flasking.

Figure 1 shows the rubber mould inside a brass flask (Varsity Upper and Lower, Ejector Type, Hanau 57-0, Waterpik, FT. Collins. CO, USA) and the lid of the mould with pouring holes.

The denture teeth were placed inside the mould. The ridge lap surface of all denture teeth was conditioned with monomer. The mould was closed and the pour-type resin was poured into the mould through the access holes. Following the manufacturer's instructions the mould was lightly tapped and left for eight minutes until the acrylic surface glazed over and became matt. At this juncture the mould was placed in a plastic bag and lowered into a pressure pot (Talleres Mestraitua Sondika Bilbao, Spain). The pot contained water

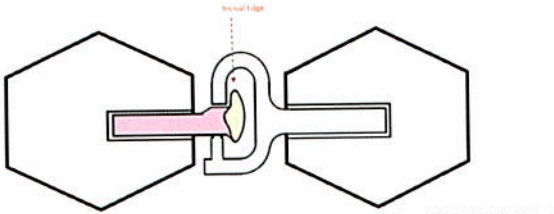

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Figure 4: Specimen mounted in tensile testing grip (Image adapted from ISO22112:2005).

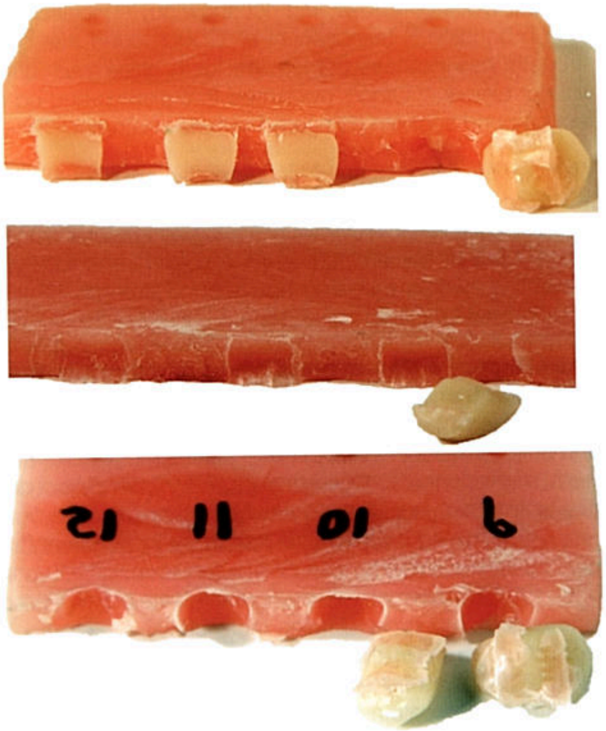

Figure 5: Fracture types. Top: the three teeth on the left show a cohesive fracture within tooth structure, the tooth on the right shows a predominantly cohesive fracture within denture resin. Middle: Clean adhesive fractures. Bottom: grooved specimens showing a mixed cohesive fracture.

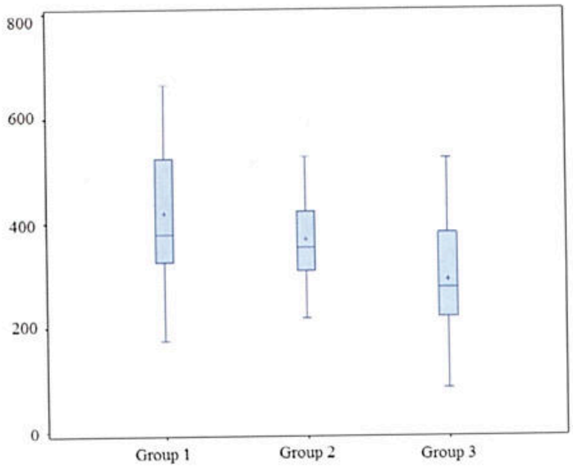

Figure 6: Box and whiskers plot showing the median, 25 and 75 percentiles.

at 55°C. The pot was closed and pressured to 2.5 bars for 30 minutes. After removal from the pot, the flask was bench-cooled for 20 minutes before opening. The specimen was taken from the flask and the sprues were cut off. The specimens were finished to conform to the ISO standard.

Specimens in Group Three were grooved on the ridge-lap surface prior to conditioning with the monomer. Figure 2 shows the ridge-lap surface of a denture tooth and the custom drill used for the grooving. The rest of the procedure was carried out as described for Group One.

For the heat-cured specimens, a wax model with the teeth in place was first poured in the rubber mould.

Figure 3 shows one specimen in the wax phase with the teeth in place, before flasking. This wax model was consequently embedded in stone in a brass denture flask and conventional denture processing procedures were applied. After closing of the flask, it was pressed to a force of three bars using a bench press (C.H. Wilhelm Wasserman, Feinwerk, Hamburg). The flask was then clamped and the acrylic polymerised in a hot water bath following manufacturer's instructions. After this, the flask was allowed to bench-cool before removing the specimen from the flask. The specimens were finished to conform to the ISO standard.

All the specimens were kept in distilled water at 37°C for 21 days before testing.

Figure 4 shows the mounting of the specimen. This specific mounting enabled a direct pull to be exerted on the incisal part of the palatal surface in a labial direction at a consistent position above the denture base polymer bar. The tests were performed at a displacement rate of 0.5mm/min, using a universal testing machine (Zwick International, Ulm, Germany), and were continued until fracture occurred.

Force values (N) at failure were captured. The mean values were compared by one-way analysis of variance using statistical software (SAS v9). The mixed procedure was used with the repeated option invoked to allow for heterogeneous variances.

One researcher examined the ridge-lap surface of the fractured denture teeth for the presence of denture base polymer using a microscope (Nikon SMZ-1 microscope, Nikon Corporation, Tokyo, Japan) at 10x magnification. The type of failure was identified as a cohesive, adhesive or a combination adhesive/cohesive type using a standard template (Table 1). The fractures were categorised according to these criteria: Cohesive in tooth = fracture interface >75% within tooth. Cohesive in resin = fracture interface >75% within resin. Cohesive mixed tooth-resin = fracture interface shared in both tooth and resin. Adhesive = fracture along the tooth-resin interface. Frequencies were tabulated and recorded. Figure 5 shows the different fracture patterns.

Table 1: Frequencies and percentages according to fracture patterns.

Group	n	Cohesive in tooth	Cohesive in resin	Cohesive mixed tooth-resin	Adhesive
1	30 (100%)	25 (83%)	0 (0%)	3 (10%)	2 (7%)
2	29 (100%)	21 (72%)	0 (0%)	8 (28%)	0 (0%)
3	39 (100%)	0 (0%)	29 (75%)	6 (15%)	4 (10%)
Total	98 (300%)	46 (155%)	29 (75%)	17 (53%)	6 (17%)

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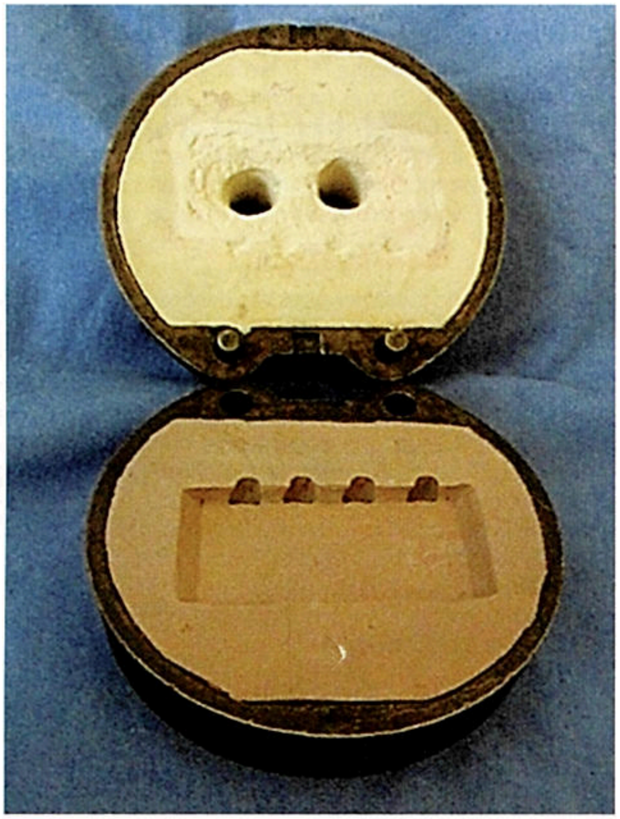
Table 2: Descriptive statistics of the values in Newtons

Group	n	Mean	Median	Std Dev	Min	Max
1	30	419.55	377.47	125.22	173.60	662.73
2	29	367.55	352.16	74.86	216.90	525.76
3	39	290.05	273.45	101.53	84.02	522.29

n = number of observations per group. **St Dev** = standard deviation. **min** = minimum. **max** = maximum.



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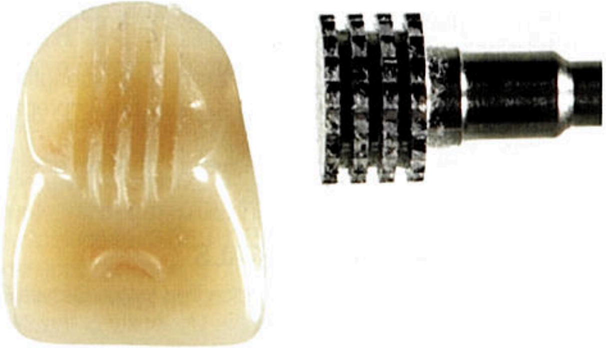

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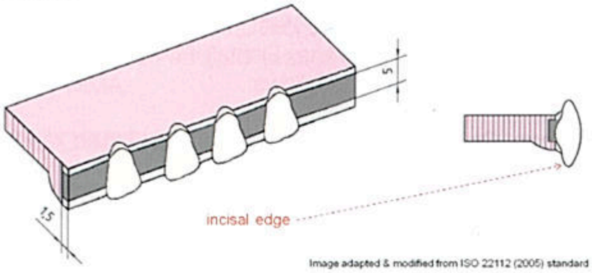

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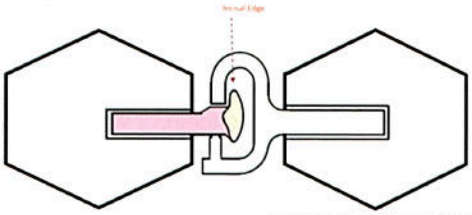

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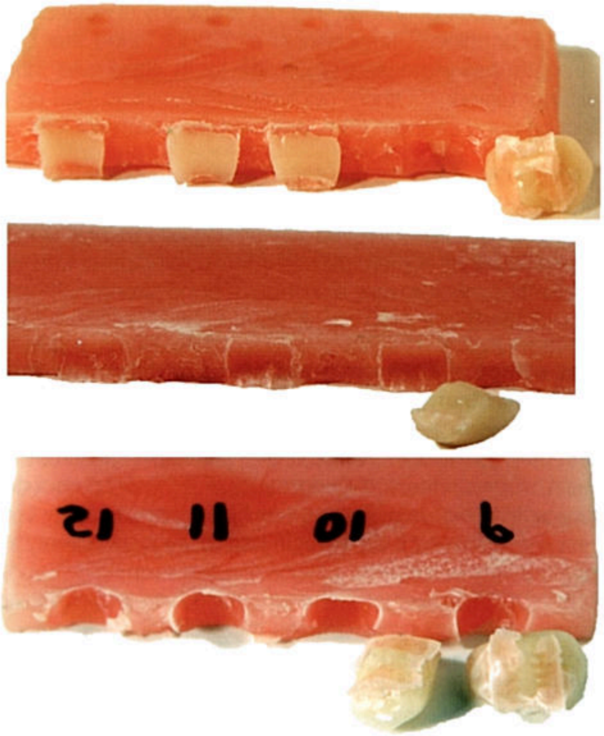

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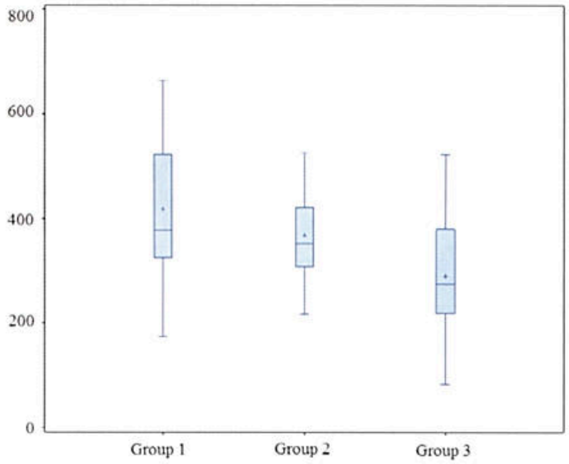

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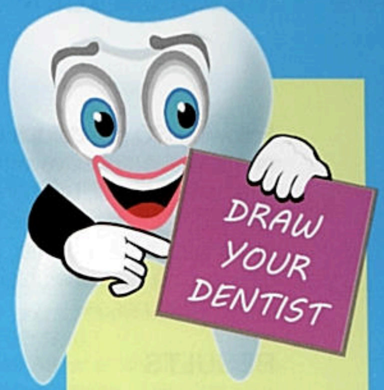

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Following ISO standard, a bond passes the test if the mode of fracture is cohesive within the tooth, or within the denture base polymer, i.e. there are remnants of tooth remaining bonded to the denture base polymer or there are remnants of denture base polymer remaining bonded to the tooth. Only a pure adhesive interfacial fracture indicates a failure of adhesion per se.

RESULTS

Table 1 shows the frequencies and percentages according to fracture types.

The descriptive statistics for the mean force at failure are shown in Table 2. The mean fracture forces were as follows, in descending order: Group One (419.55N); Group Two (367.55); Group Three (290.05N). Figure 6 shows the box and whiskers plot for the three groups.

The results of the analysis of variance showed a significant difference in the mean force at failure among the groups ($p<0.0001$). The estimated difference in means was 77.5 with a 95% confidence interval estimate of the difference being (34.8, 120.2). Mean fracture force for Group Three (pour-type resin with grooved teeth) was significantly lower than for Group Two (pour-type, teeth not-grooved) ($p=0.0006$) and for Group One ($p<0.0001$). The mean force values for Groups One and Two were not quite significantly different ($p=0.0627$).

DISCUSSION

This investigation studied the bond strength and failure patterns of resin denture teeth bonded to a pour-type and a heat-cured denture base resin. It also investigated the effect on the bond strength of grooving the ridge-lap surface of anterior denture teeth using a drill supplied specifically for that purpose.

Within the limitations of the study, null-hypothesis 1 was: "There is no difference in bond strength using a pour-type denture base material and a conventional heat-polymerised resin" can be accepted; null-hypothesis 2: "There is no difference in bond strength between prepared ridge-lap surfaces and unprepared ridge lap surfaces" is not accepted; null-hypothesis 3: "The type of bond failure (adhesive or cohesive) does not differ between the groups" is partially accepted. Failure for Groups One and Two was predominantly cohesive within the teeth. Failure for the grooved specimens of group Three was also predominantly cohesive but within the denture base material.

The reasons for the difference in group sizes are the following: One tooth from one specimen from each of Groups Two and Three was lost due to operator error during handling of the universal testing machine. Testing for Group Three was done following the completion of testing Groups One and Two. At that stage, the distributor for the denture teeth supplied more teeth than requested and the researchers decided to use all of them. The statistician confirmed that the different group sizes did not affect the analysis of the results.

Published standards are not designed for research purposes, but to guide the industry on minimally accepted product requirements. Although an older version of the ISO standard (ISO 3336. Dentistry – synthetic resin teeth, 1993) specifies a bond strength (31MPa), the newest ISO standard does not give bond strength criteria. According to ISO, the bond between denture teeth and denture base is simply considered inadequate in case of an adhesive failure. Despite the through trials on the universal testing machine were subjected to statistical analysis.

Mean force at failure for Group One was the highest. However, the difference between the means, with Group Two the second strongest group, was not statistically significant. Therefore, for this type of denture teeth, different PMMA's did not influence bond strength. Their fracture patterns did not differ either. Both groups resulted in predominantly cohesive fractures within the denture teeth. The denture teeth were identified as the weakest link in the system.

Adhesive debonding of teeth may be the result of incompatible surface conditions at the tooth/denture interface.[5] Some acrylic resin teeth are modified to increase wear resistance by adding cross-linking agents and fillers.[36] These cross-linked acrylic resin artificial teeth are reported to have lower bond strength to denture base resin compared with conventional acrylic resin teeth.[11] Comparing the fracture types of this study with those seen in previous studies confirms that the type of denture tooth plays a role in the failure process. The teeth used in this research consisted of a double layer PMMA and dimethacrylate, without filler.[36] It may be worthwhile to identify the type of tooth before a decision is made on ridge lap modification.

Fracture patterns assessed in this study, being predominantly cohesively within the tooth itself for Groups One and Two, confirms previous observations that the bond between this type of denture tooth and the base material is excellent and that the tooth itself is the weakest part in the denture/tooth unit. However, when the denture tooth is grooved, the fracture pattern changes. Now, the fracture happens predominantly cohesively within the denture base material. The grooving seems to have a reinforcing effect on the tooth, up to the point that the tooth, tagged by denture base resin, becomes stronger than the resin. However, analysing the fracture patterns together with the force values at failure, Group Three was still significantly weaker than the two other groups. Why the denture base resin is more susceptible to fracture when bonding to a grooved tooth, needs to be investigated further.

An interesting finding following a finite element study by Darbar *et al.* (1993) was that load application to the upper incisors produced a maximum concentration of tensile stresses within the body of the tooth and not at the tooth-denture interface.1 This stress analysis study complements the findings of our study: with no grooving of the denture teeth, separation of the tooth from the PMMA base happened within the body of the denture tooth. This also confirms that the recommended ISO testing method produces a situation simulating incisal guidance of a denture.

The predominantly cohesive failures in this study showed that bonding between tooth and denture base resin was successful. Very few adhesive fractures occurred. Adhesive failures seen in clinical practice may be due to incompatibility of denture base resin and denture teeth, and may also be owing to laboratory error in the case of compatible materials.

When the ridge-lap surface of the denture teeth were grooved, the cohesive fractures occurred in the denture base resin and the teeth remained intact. For conventional denture work, this has the advantage that the same tooth may be used for repair purposes. However, for (implant-) overdentures, this type of fracture may jeopardise the integrity of the whole prosthesis, and a cohesive break within the tooth itself may be the prethis study, no grooving of denture teeth is recommended for implant-supported overdentures.

The specimens were not subjected to thermal and cyclic loading. This may be considered a study limitation, even though thermal and cyclic loading lead to conflicting results in previous studies. According to Kelly, correlation of *in vitro* studies with clinical performance is unpredictable for materials that are subjected to complex function over a long period of time, such as for dentures.[6] Therefore, it is suggested that *in vitro* findings are supplemented by clinical trials.

Differences in the types of denture teeth, acrylic resin and in methodology may explain the variation in reported results.

CONCLUSIONS

Within the limitations of this study, it is concluded that bonding strength of denture teeth to a pour-type denture base resin was similar to bonding strength to a heat-cured resin base. Failures were predominantly of a cohesive nature within the body of the teeth.

Ridge-lap modification of resin teeth by means of grooving reduced the fracture resistance of the tooth-denture base unit.

Despite numerous investigations on bond strengths between teeth and denture base resins, no recommendations on compatible combinations have been reported. This may be attributed to the lack of standardisation of testing, and the numerous types of denture teeth and denture base resins on the market.

It is recommended that a scientific systematic review of the literature is performed in the endeavour to identify compatible combinations of denture tooth, ridge-lap modification and denture base material.

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