

Bonding of resin teeth to the polymethyl methacrylate denture base material

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The objective of this study was to compare bonding of acrylic resin teeth treated in various ways to the polymethyl methacrylate (PMMA) denture base material. The joint surface of each acrylic tooth cured to heat-cured or autopolymerizing PMMA was either untreated, ground, or adjusted with mechanical retention. The bond to the PMMA was tested with a three-point loading test. To determine whether the bond failure was adhesive or cohesive, the fracture surfaces were analyzed visually and by scanning electron microscopy. The highest bond strength to both the heat-cured and the autopolymerizing PMMA was obtained by grinding grooves on the joint surface of an acrylic resin tooth before it was cured to the PMMA ($p < 0.001$). Heat-cured PMMA did not adhere to the acrylic resin tooth better than the autopolymerizing PMMA did ($p > 0.05$). □ *Acrylic resins; bond strength; dentures; tooth, artificial*

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One of the commonest types of failure in a denture is bond failure between an acrylic resin tooth and an acrylic resin denture base (1, 2). Increased use of the pour type of denture base resin has increased bond failures because its physicochemical properties are poorer than those of heat-cured acrylic resin (3). Acrylic resin tooth failures have also been reported in implant-supported dentures (4, 5). Unfortunately, those studies did not report precise information on the failure type. Consequently, adhesion between an acrylic resin tooth and the denture base evidently has clinical implications.

The composition of an acrylic resin tooth is essentially cross-linked polymethyl methacrylate (PMMA) (6). The cross-linking PMMA is not evenly distributed in the tooth structure; for example, the gingival ridge-lap area may not be as highly cross-linked as the incisal area of the tooth. This will, at least in theory, facilitate better chemical bonding between the tooth and the PMMA of the denture base. When Spratley (7) tested how wetting the ridge lap of an acrylic resin tooth with methyl methacrylate (MMA) affects the bond strength between the tooth and PMMA, the results were poor. Unfortunately, he did not report the MMA wetting time, which has recently been shown to be an important factor in the adhesion between acrylic resins in repair (8). The use of mechanical retention is a primary means of securing the bond between acrylic resin teeth and the denture base PMMA. The grooves increase the surface area of the ridge lap, and it seems to be possible that it also improves bond strength. There are at least two studies (9, 10), with somewhat differing results, on the effect of grooves on bonding of the tooth to the denture base PMMA. Thus, this problem would also seem to require further investigation.

The aim of this study was to compare the various mechanical treatments of the ridge lap of the acrylic resin teeth by determining the strength of their bonding to the denture base PMMA. Both heat-cured and autopolymerizing PMMA were tested, and the results were confirmed by scanning electron microscopy.

Materials and methods

Pink heat-cured and autopolymerizing PMMA (Pro Base Hot and Pro Base Cold, Ivoclar, Schaan, Liechtenstein) were used as base material for the test specimens into which the Vitapan (color A4 on the Vita scale) cross-linked acrylic resin teeth (Vita Zahnfabrik GmbH, Bad Sackingen, Germany) were bonded. The test specimen including the acrylic resin tooth (Fig. 1) was prepared in a conventional gypsum mold. The ratio of PMMA powder to MMA liquid was 22.5 g powder to 10 ml monomer for heat-cured PMMA and 20.5 g powder to 10 ml monomer for autopolymerizing PMMA. Heat-cured PMMA was polymerized in boiling water for 40 min, and autopolymerizing PMMA was treated in a pneumatic curing unit (Acri-Dense 3, GC-America Inc., Chicago, Ill., USA) with an air pressure of 200 kPa (2 bar) for 15 min. The temperature of the curing water was +40°C. After being polymerized the test specimens were ground to the predetermined dimensions (Fig. 1) and stored in water at room temperature for 24 h before testing.

The acrylic resin teeth incorporated into the test specimens were treated in various ways in accordance with the group to which they belonged (Table 1). Fig. 2 illustrates the ridge laps of the untreated tooth and the teeth after their mechanical treatment. The surface

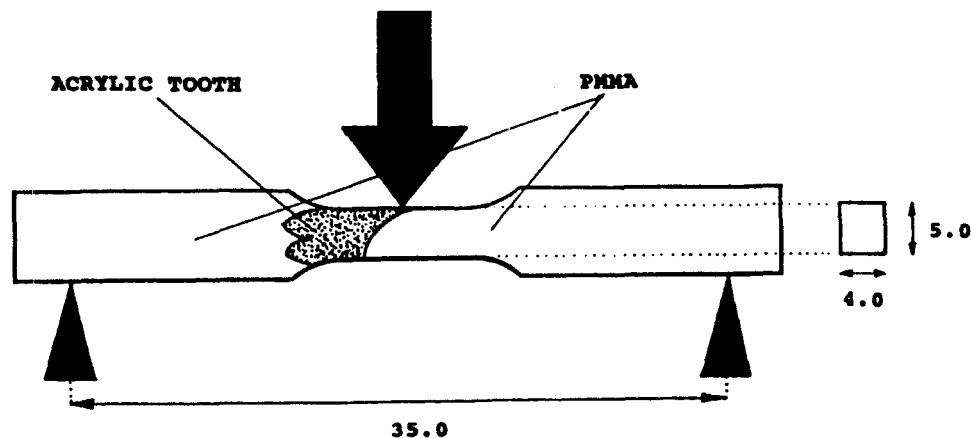


Fig. 1. Schematic drawing of the test specimen and the loading method used in this study. Dimensions in millimeters.

was ground with 120-grit sand paper. The specific treatment of the ridge lap was followed by dissolving the surface with MMA for 180 sec at room temperature. Shortly after the ridge lap was dissolved, the teeth were incorporated into the acrylic resin dough and pressed with a pressure of 10,000 kPa (100 bar) for 10 min.

The fracture force of the test specimen was measured with a Schleuniger 2E testing machine (Schleuniger, Solothurn, Switzerland) at a crosshead speed of 120 mm/min, which had also been used in the previous study (11–13). The span of the three-point loading test was 35.0 mm (Fig. 1). The transverse strengths (S) were calculated by means of the following formula:

$$s = \frac{3WL}{2bd^2}$$

where W is the fracture force, L is the distance between supports, b is the specimen width, and d is the specimen thickness.

After the test specimens were fractured, the fracture surfaces were analyzed by visual examination to determine whether the failure was adhesive or cohesive. The

failure was considered 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. The failure surfaces were also examined in the scanning electron microscope (SEM) (Jeol JSM 35, Jeol Inc., Tokyo, Japan) at 15 kV accelerating potential. The thickness of sputtered gold on the sample surface was 70 nm. The original magnification of the photomicrographs taken of the failure surfaces was 200 \times . To ensure that the PMMA had penetrated properly into the retention holes of the teeth (groups 14 and 24), the teeth were cut vertically and inspected by SEM at a magnification of 36 \times .

Mean values and standard deviations were calculated for the fracture force values, and the means within groups of the same PMMA type were compared by one-way analysis of variance (ANOVA). The means for groups with similar treatment of the joint surfaces—that is, the means for the heat-cured PMMA and those for autopolymerizing PMMA—were compared by means of Student's t test.

Results

Mean values for the fracture force of groups 11–14 varied from 53 to 134 N (Table 2), and the calculated transverse strengths varied from 28 to 71 MPa. The means of the heat-cured PMMA groups varied statistically significantly ($p < 0.001$), and the best bond between an acrylic resin tooth and the base material PMMA was obtained with two grooves on the ridge lap (group 13).

The means within the autopolymerizing groups also varied statistically significantly ($p < 0.001$), and the greatest bond strength was obtained with two grooves on the ridge lap (group 23). The bonding of an acrylic resin tooth to the heat-cured PMMA and that of the same type of tooth to the autopolymerizing PMMA did not differ statistically significantly between groups 11

Table 1. Classification of the test specimens on the basis of type of polymethyl methacrylate (PMMA) and treatment of the joint surface of an acrylic tooth

Group	Treatment	Type of PMMA
11	Untreated	Heat-cured
12	Ground	Heat-cured
13	Ground and two grooves	Heat-cured
14	Ground and 1.5-mm-diameter retention hole	Heat-cured
21	Untreated	Autopolymerizing
22	Ground	Autopolymerizing
23	Ground and two grooves	Autopolymerizing
24	Ground and 1.5-mm-diameter retention hole	Autopolymerizing

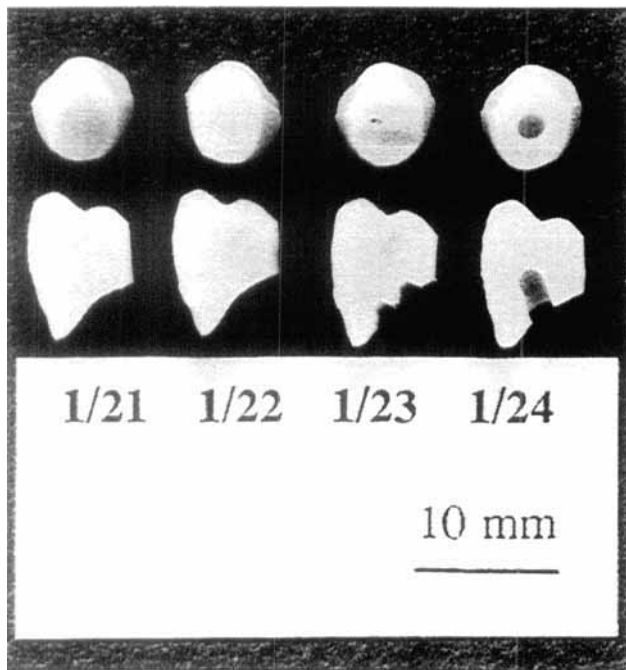


Fig. 2. Mechanical treatments of the joint surfaces of the acrylic resin tooth according to group to which the test specimens belonged.

and 21, 13 and 23, or 14 and 24 ($p > 0.05$), whereas there was a slight difference between groups 12 and 22 ($p = 0.001$).

Visual examination of the failure surfaces showed that the number of adhesive failures decreased when the joint surface was ground (Table 3). The SEM photomicrographs (Figs. 3a,b) of groups 11 and 21 showed slightly better adhesion of heat-cured PMMA to the surface of a mechanically untreated tooth than to that of autopolymerizing PMMA. Grinding of the joint surface of the tooth improved the adhesion (Figs. 3c and d). Inspection of the retention holes (groups 14 and 24) showed that neither heat-cured nor autopolymerizing

Table 2. Fracture forces (\pm SD) and transverse strengths of the test specimens ($n = 5$ in each group). Group 11–14: heat-cured polymethyl methacrylate (PMMA); group 21–24: autopolymerizing PMMA

Group	Load (N)	Strength (MPa)
11	53.0 \pm 12.5	27.8
12	131.6 \pm 29.6	69.1
13	134.2 \pm 28.2	70.7
14	95.1 \pm 9.7	49.1
21	48.7 \pm 11.7	25.6
22	81.7 \pm 14.6	42.9
23	131.5 \pm 43.8	71.1
24	108.8 \pm 24.7	57.1

Table 3. Number of adhesive and cohesive failures ($n = 5$ in each group)

Group	Adhesive failures	Cohesive failures
11	5	0
12	3	2
13	1	4
14	2	3
21	5	0
22	4	1
23	1	4
24	1	4

PMMA had completely penetrated into the retention hole of the teeth (Fig. 4a). Inspection of the fracture surface showed that the bond fracture in the area of the retention hole occurred at the same level as the ridge lap (Fig. 4b).

Discussion

A recent study of the strength of repaired PMMA (8) led to the present investigation, which has dealt with a similar problem—that is, the adhesion between PMMA interfaces. The fracture force testing method used in the present study has been used previously by me, and the transverse strengths of the specimens obtained in this study can be compared with the measurements from previous investigations (8, 11–13). The transverse strength of the autopolymerizing PMMA was lower than that of heat-cured PMMA, as has also been reported previously (6). The transverse strength of test specimens that included an acrylic resin tooth was lower than that of plain heat-cured PMMA. This finding can possibly be explained by the residual stresses during loading at the interface of the acrylic resins of different compositions; that is, some stresses might exist in the acrylic resin around the tooth.

The shape of the ridge lap of the acrylic resin tooth can be contoured for optimal adhesion, as can the repair surface of dentures (14). However, the results of studies in which various mechanical methods of improving the adhesion have been compared have mainly been contradictory (9, 10, 15, 16). The present study is also an attempt to tackle this question. Here the results showed a clear increase in the fracture force—that is, in the bond strength between the acrylic resin tooth and the PMMA base material—when there were grooves on the joint surface of the tooth. This supports the finding of Hugget et al. (16): the contact areas between the tooth and the PMMA base material differ considerably in terms of bond strength.

The poorer strength of the bond to the PMMA base material of the tooth with retention holes compared with that with the grooves seems at the first impression

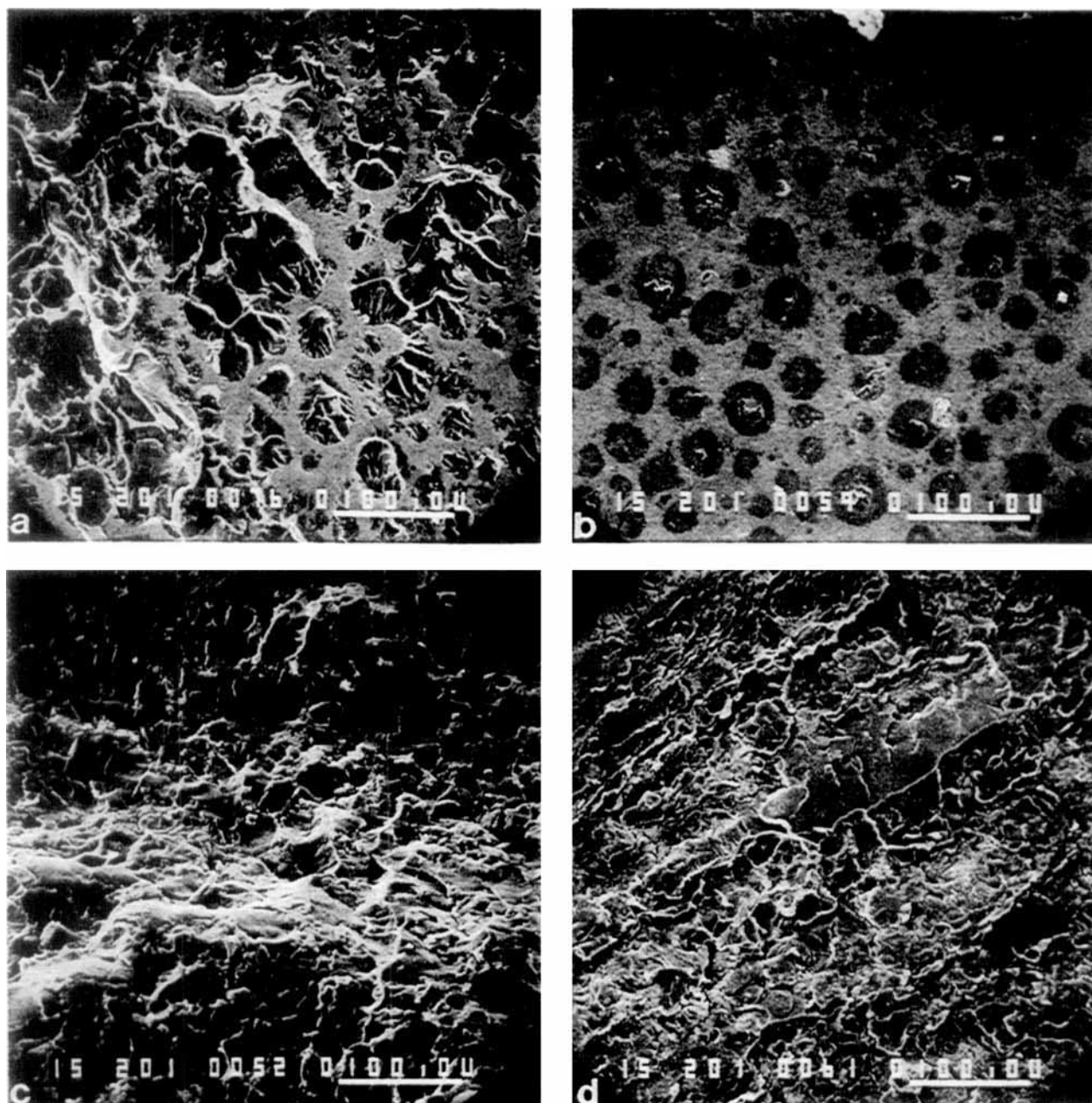


Fig. 3. Scanning electron photomicrographs of the bond fracture surface of an acrylic resin tooth. 3a) Heat-cured; 3b) autopolymerizing methacrylate (PMMA) bonded with no mechanical treatment on the ridge lap; 3c) polymethyl heat-cured; 3d) autopolymerizing PMMA bonded to the ground ridge lap of the acrylic resin tooth (magnification, 200 \times ; the bar = 0.1 mm).

to be due to improper penetration of PMMA into the hole. The SEM photomicrographs clearly showed void spaces inside the teeth that had retention holes. This improper penetration is obviously caused by air trapped in the hole when the acrylic resin dough was pressed. Porcelain teeth with retention holes include small horizontal holes that enable the air to escape during pressing of the acrylic resin dough. Improper penetration was

not, however, the reason for the lower bond strength. The bond fracture in the region of the retention hole occurred at the same level as the ridge lap. Consequently, the empty spaces at the bottom of the retention holes seemed not to contribute to bond failure.

The aforementioned finding gave rise to speculation about the fracture mechanics in that particular area of the denture. The PMMA in the retention hole is affected

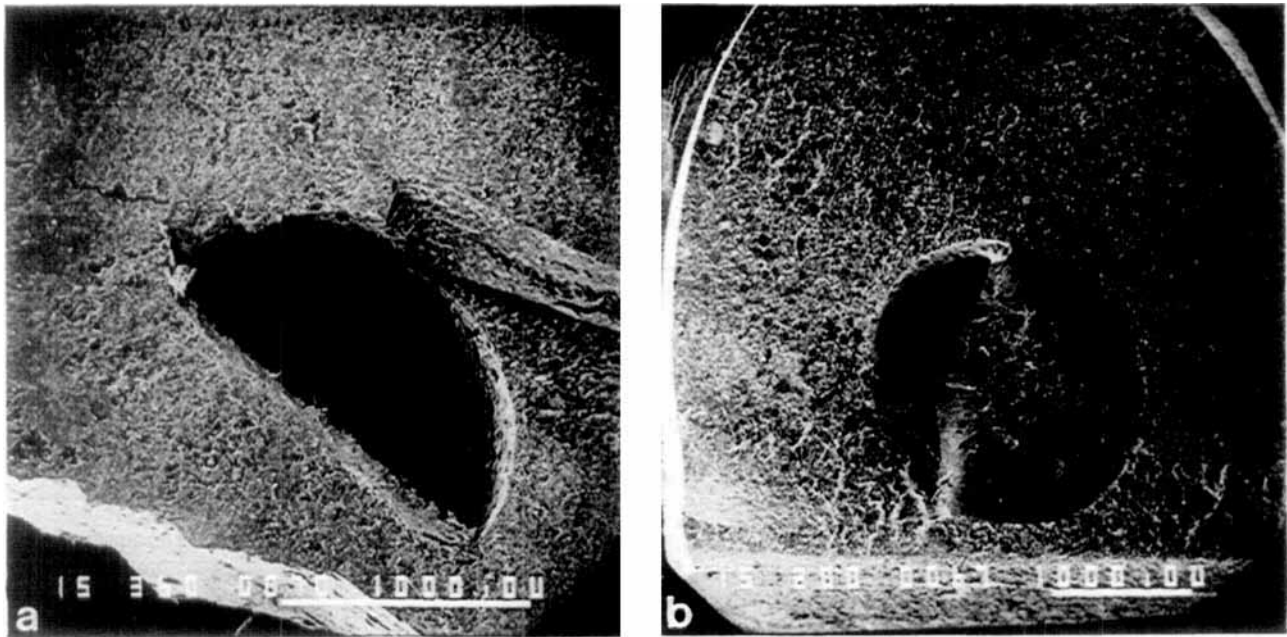


Fig. 4. Scanning electron photomicrographs from a vertical section of an acrylic resin tooth. 4a) Shows the empty space at the bottom of the retention hole (magnification, 36×; the bar = 1.0 mm); 4b) bond fracture surface from the area of a retention hole (magnification, 20×; the bar = 1.0 mm).

by bending stress during mastication (Fig. 5a). When the base of the retention hole is beveled, the occlusal biting force affects the shear stress on the base of the hole and enlarges the dimensions of the tap (Fig. 5b). Obviously, the interface between the acrylic resin tooth and the denture base PMMA is more resistant to shear forces than to tensile forces. This hypothesis would also explain the high bond strength of the acrylic resin tooth with two retention grooves to the denture base PMMA (Fig. 5c). Furthermore, in Fig. 5c no obvious fracture point could be detected in the PMMA base. This

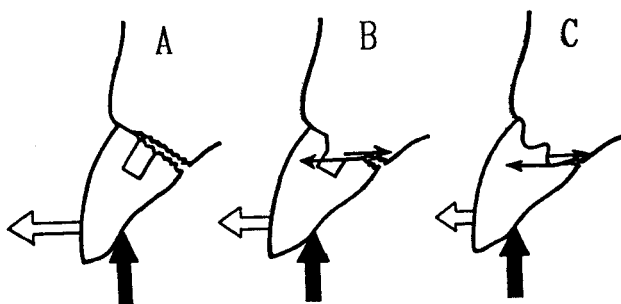


Fig. 5. Schematic drawing of the fracture mechanics of an acrylic resin tooth from a denture base. 5a) Unbeveled retention hole; 5b) beveled retention hole; and 5c) two retention grooves. The black arrow indicates the direction of the occlusal biting force, the light arrow indicates the fracture direction, and the small arrows indicate the shear forces.

together with the larger contact area could explain the high bond strength.

The technical laboratory factor that contributes the bond strength of the acrylic resin tooth to the denture base PMMA is surface contamination. The joint surface can be contaminated with denture wax (17) or by a tinfoil substitute such as sodium-alginate (18), both of which decrease the bond strength. To improve adhesion between an acrylic resin tooth and the denture base PMMA, it is also possible to use high-impact PMMA (that is, butadiene-grafted PMMA), which, according to previous reports, adheres to the tooth surface better than standard PMMA does (10). However, a result that contradicts this finding has also been published (19).

A factor assumed to be important for bond strength is that the joint surface of the acrylic resin tooth must be adequately dissolved. In this study the period used for dissolving the joint surface with MMA before the acrylic resin dough was packed was 180 sec. Other solvents, such as methylene chloride added to MMA (6), have been used to hasten the dissolution of the joint surface of the acrylic resin tooth. Whether the MMA dissolving period used was effective compared with shorter time periods was not established in this study.

The results of the present study suggest that in both heat-cured and autopolymerizing PMMA, proper grinding of the ridge lap of an acrylic resin tooth with two horizontal retention grooves yields to the highest bond strength.

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