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Evaluation of the Bond Strength of Denture Base Resins to Acrylic Resin Teeth: Effect of Thermocycling

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Abstract

Purpose: The purpose of this study was to evaluate the thermocycling effects and shear bond strength of acrylic resin teeth to denture base resins.
Materials and Methods: Three acrylic teeth (Biotone, Trilux, Ivoclar) were chosen for bonding to four denture base resins: microwave-polymerized (Acron MC), heat-polymerized (Lucitone 550 and QC-20), and light-polymerized (Versyo.bond). Twenty specimens were produced for each denture base/acrylic tooth combination and were divided into two groups ($n = 10$): without thermocycling (control groups) and thermocycled groups submitted to 5000 cycles between 4 and 60°C. Shear strength tests (MPa) were performed with a universal testing machine at a crosshead speed of 1 mm/min. Statistical analysis of the results was carried out with three-way ANOVA and Bonferroni's multiple comparisons post hoc analysis for test groups ($\alpha = 0.05$).
Results: The shear bond strengths of Lucitone/Biotone, Lucitone/Trilux, and Versyo/Ivoclar specimens were significantly decreased by thermocycling, compared with the corresponding control groups ($p < 0.05$). The means of Acron/Ivoclar and Lucitone/Ivoclar specimens increased after thermocycling ($p < 0.05$). The highest mean shear bond strength value was observed with Lucitone/Biotone in the control group (14.54 MPa) and the lowest with QC-20/Trilux in the thermocycled group (3.69 MPa).
Conclusion: Some acrylic tooth/denture base resin combinations can be more affected by thermocycling; effects vary based upon the materials used.

One of the most common denture repairs is the replacement of detached acrylic resin teeth.[1-4] Huggett et al[5] reported that approximately 30% of all denture repairs carried out by three dental laboratories were due to debonded/detached acrylic teeth. Given that one of the advantages of acrylic teeth is the ability to chemically bond to denture base resins,[6-9] one probable explanation for this type of failure would be the presence of impurities on the tooth surface. Impurities could include residual wax[10,11] because of incomplete elimination or contamination of the ridge-lap surfaces with tin-foil substitutes.[12] Such materials can prevent chemical bonding between acrylic teeth and denture base resins.[10] Other factors could influence the bond strength between teeth and denture base resins, including chemical or mechanical preparation on the ridge-lap surface of the tooth,[8,13] and processing variables such as resin dough time and polymerization cycle.[14]

The ability of acrylic teeth to bond to denture base resins may also be affected by the type of denture teeth.[8,15] Conventional acrylic resin teeth usually achieve a better bond to denture base resins than do highly cross-linked teeth.[15]

Different types of denture base resins also affect the bond between acrylic teeth and denture base resins. Several studies have compared the bonding of acrylic teeth to microwave-polymerized, light-polymerized, heat-polymerized, and autopolymerizing denture base resins,[16-22] and observed that heat-polymerized resins revealed the highest bonding values.[1-3,7,8,17,18,20-22] Some studies[16,19] demonstrated higher bond strengths of acrylic teeth to microwave-polymerized denture base resins than with heat-polymerized denture base resins.

Visible light-cured (VLC) denture base resins have been promoted as an alternative to heat-polymerized or microwave-polymerized denture base resins for many prosthodontic applications since the introduction of Dentsply Triad VLC resin (Dentsply International, Inc., York, PA);[7,17] however, the results from some studies showed that the bond between VLC denture base resins and acrylic teeth could be weaker than

Table 1 Acrylic resin teeth used

Tooth	Manufacturer
Biotone/30M	Dentsply Ind. e Com. Ltd.—Rio Janeiro, Brazil
Trilux/M5	RuthiBras Imp. Exp. e Com. De Odontológicos Ltd.—Pirassununga, Brazil
Ivoclar/Gnathostar D86	Ivoclar Vivadent Ltd.—São Paulo, Brazil

the bond of heat-polymerized resins and microwave-activated resins.[17,18,20,23]

Among the previously considered factors, studies have addressed the degradation at the acrylic teeth/denture base resin interface as a result of thermal stress. In fact, some studies[21,24] have indicated that thermocycling can negatively affect the bond strength between acrylic denture teeth and denture base resins.

Studies have investigated the effect of different denture base resins and acrylic denture teeth on the bond strength between acrylic teeth and the denture base; however, new materials have been developed, and it is necessary to select more compatible denture base resins and acrylic teeth combinations to reduce the number of prosthesis fractures and acrylic teeth detachments.[22] Thus, the aim of this study was to determine the shear bond strength of heat-, microwave-, and light-polymerized denture base resins to acrylic resin teeth after thermocycling. The null hypothesis tested was that the bond strength of denture base resins to acrylic denture teeth would not be affected by thermocycling.

Materials and methods

Bond strengths of acrylic resin teeth to denture base resins were evaluated before and after thermocycling. Three acrylic resin teeth (Table 1) were chosen for bonding to four denture base resins (Table 2).

Twenty specimens were produced for each denture base/acrylic resin denture tooth combination for a total of 240 specimens. The specimens were composed of denture base resin cylinders bonded to the ridge-lap surface of the acrylic denture teeth (Fig 1). All acrylic resin denture teeth were maxillary molars. The ridge-lap surfaces of the denture teeth were reduced using 320-, 400-, and 600-grit silicon carbide paper (Norton, Saint-Gobain Abrasivos Ltd., Vinhedo, Brazil) in a polishing machine (Arotec Ind. e Com. Ltd., Cotia, Brazil) at 300 rpm to obtain a flat surface for bonding to the denture base resin. Each denture tooth was embedded in autopolymerizing polymer (poly)methyl methacrylate (PMMA) (Jet, Artigos Odontológicos Clássico Ltd., São Paulo, Brazil) using an embedding machine (Arotec Ind. e Com. Ltd.). The ridge-lap surface of the embedded tooth was then polished with 600-grit silicon carbide paper.

Silicone patterns (Zetalabor, Zhermack S.A., Rovigo, Italy) with a circular opening (5.0 mm diameter × 2.5 mm length) were obtained from a stainless steel mold to standardize the dimensions of the denture base resin cylinders (Fig 2).

Cyanoacrylate glue (Super Bonder, Loctite Henkel Ltd., Diadema, Brazil) was applied to the silicone pattern PMMA/polymer interface, so the silicone pattern opening position coincided with the prepared ridge-lap surface. Then, the circular opening of the silicone pattern was sealed with a small amount of silicone (Zetalabor) before proceeding with the investing. The embedded tooth and the silicone pattern were then invested in denture flasks using dental stone (Herodent, Vigodent S.A. Ind. Com., Rio de Janeiro, Brazil). Standard metal flasks (OGP, Produtos Odontológicos Ltd., São Paulo, Brazil) and plastic flasks (Onda Cryl, Artigos Odontológicos Clássico Ltd.) were used for heat polymerization (Lucitone 550 and QC-20) and microwave polymerization (Acron MC), respectively. After the dental stone was set, the flask was opened, and the silicone was carefully removed from the silicone pattern circular opening. Microwave- and heat-polymerized denture base resins were packed and processed according to the manufacturer's instructions (Table 2). After polymerization, each flask was bench cooled at room temperature overnight. The specimens were carefully deflasked, cleaned, and stored in distilled water at 37°C for 50 ± 2 hours.[24]

According to the light-polymerized acrylic resin manufacturer's instructions, first, the ridge-lap surface of the acrylic denture teeth was roughened with a diamond-coated grinder no. 6 (Labordental, São Paulo, Brazil) at 18,000 rpm. The silicone pattern was glued as described above. Next, the bonding agent (Versyo.bond) was painted on the ridge-lap surface of the acrylic denture teeth and then polymerized for 30 seconds in a light-curing unit (Heralight Pre, Heraeus Kulzer South America Ltd., São Paulo, Brazil). Then, the Versyo.bond acrylic resin was pressed onto the circular opening of the silicone pattern and was polymerized according to the manufacturer's instructions (Table 2). The specimens were stored in distilled water at 37°C for 50 ± 2 hours.[24]

Table 2 Denture base resins used

Denture base resin	Manufacturer	Type	Polymerization cycle*
Acron MC	GC Lab Technologies, Inc.—Alsip, IL	Microwave-polymerized	3 minutes at 500 W
Lucitone 550	Dentsply Ind. e Com. Ltd.—Rio de Janeiro, Brazil	Heat-polymerized	90 minutes at 73°C and 100°C for 30 minutes
QC-20	Dentsply Ind. e Com. Ltd.—Rio de Janeiro, Brazil	Heat-polymerized	20 minutes at 100°C
Versyo.bond	Heraeus Kulzer South America Ltd.—São Paulo, Brazil	Light-polymerized	Prepolymerization for 10 seconds and final polymerization for 4.5 minutes

*Polymerization cycles recommended by the manufacturers.

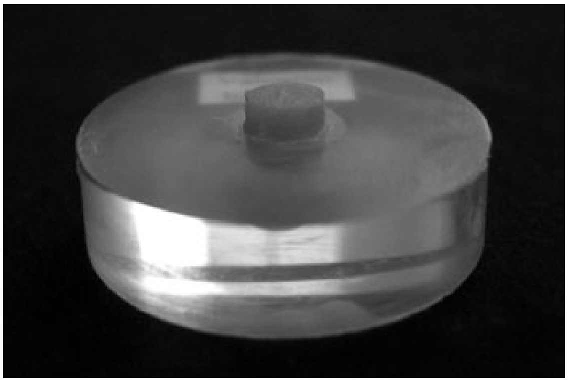

Figure 1 Test specimen used in this study.

After water storage, the 20 specimens of each denture base/denture tooth combination were divided into two groups (n = 10). Control specimens were tested without thermocycling. The other specimens were thermocycled for 5000 cycles[25,26] between 4 and 60°C[15,27] with a dwell time of 30 seconds[7,24] in each bath, using a thermocycling machine (MSCT-3, Elquip, São Carlos, Brazil).

A universal testing machine (EMIC-DL 3000, EMIC Ltd., Curitiba, Brazil) was used with a 2 kN load cell, and the shear loading was applied at a crosshead speed of 1 mm/min.[28] The maximum stress (MPa) required to shear the denture base resin off the tooth was considered as the shear bond strength. Factors (thermocycling, denture base resins and acrylic teeth) affecting the response variable shear bond strength were analyzed by three-way ANOVA, and a Bonferroni post hoc test was used to determine differences between mean values ($\alpha = 0.05$).

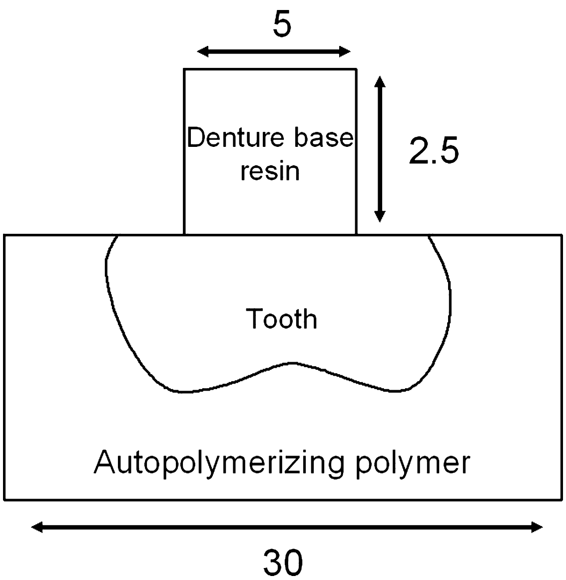

Figure 2 Schematic drawing of the specimen. Dimensions in millimeters.

Results

The three-way ANOVA results (Table 3) indicated a significant difference for the interactions of denture base resins and acrylic denture teeth with thermocycling ($p < 0.001$). In Figure 3, the results of the effect of thermocycling on the shear bond strength of each acrylic denture tooth/denture base resin combination are illustrated. Thermocycling resulted in a significant reduction in the bond strength between Lucitone 550 denture base resin and Biotone and Trilux teeth ($p < 0.05$). A similar effect was observed for the Versyo.bond denture base resin and Ivoclar teeth. Figure 3 also shows that thermocycling significantly improved the bond strength of Acron MC and Lucitone 550 denture base resins when combined with Ivoclar teeth ($p < 0.05$).

Mean and standard deviation values of specimens' shear bond strengths are shown in Table 4. In the control group, the lowest mean shear bond strength was seen with QC-20/Ivoclar (4.14 MPa), and the highest was seen with Lucitone/Biotone (14.54 MPa). After thermocycling, the lowest shear bond strength was seen with QC-20/Trilux (3.69 MPa), and the highest was seen with Lucitone/Ivoclar (11.03 MPa).

Discussion

The null hypothesis of the present study, stating that the bond strength of denture base resins to acrylic denture teeth would not be affected by thermocycling, was rejected. Although thermocycling did not significantly affect most of the combinations of the acrylic denture tooth and the denture base resin, there was a significant reduction in mean shear bond strengths of Lucitone 550 denture base resin with Biotone and Trilux teeth. A similar effect was observed for Versyo.bond denture base resin and Ivoclar teeth. This indicates that some denture base resin/acrylic tooth combinations can be more affected by thermocycling. A decrease in the bond strength after thermocycling was also found in several other studies.[4,15,21,24,26] In the present study, thermocycling was used to more closely simulate the oral condition and to assess the durability of the bond among materials.[22] The decrease in these materials' bond strengths may possibly be explained by water absorption and thermal expansion coefficient differences for each material.[21] Based on this hypothesis, the diffusion of water molecules through the acrylic denture tooth/denture base resin interface may result in bonding failure, causing a decrease in the bond strength. Differences between thermal coefficients can also adversely affect the bond of acrylic denture teeth to denture base resins.[24] Materials with different thermal expansion coefficients also present different degrees of shrinkage and expansion. That process promotes the fatigue phenomenon of these materials, rupturing their bond. In addition, cyclical stress may cause any debonded regions at the acrylic denture tooth/denture base resin interface to grow progressively in size.

On the other hand, a significant improvement in the shear bond strength of Acron MC and Lucitone 550 denture base resins with Ivoclar teeth was observed. These results disagree with those reported by El-Sheikh and Powers,[24] Chai et al,[15] Amin,[21] Kim et al,[26] and Patil et al.[4] Differences in the thermocycling protocol might have been the reason for the different findings. There is no standardization for thermocycling times in

Table 3 Results of three-way ANOVA

Source of variation	Sum of squares	*df*	Mean square	*F*	*p*
Thermocycling	24.693	1	24.693	3.481	0.063 (ns)
Denture base resin	1032.645	3	344.215	48.526	<0.001*
Acrylic teeth	105.652	2	52.826	7.447	0.001*
Thermocycling × Denture base resin	147.264	3	49.088	6.920	<0.001*
Thermocycling × Acrylic teeth	136.412	2	68.206	9.615	<0.001*
Denture base resin × Acrylic teeth	342.413	6	57.069	8.045	<0.001*
Thermocycling × Denture base resin × Acrylic teeth	309.135	6	51.522	7.263	<0.001*
Error	1702.423	240	7.093		
Total	3800.636	263			

*Significantly different; $p < 0.05$.
(ns), no significant difference; $p > 0.05$.

the different studies. A direct comparison between the results of the present study and those of others is somewhat difficult because there has been no standardization of testing techniques in the dental literature and because of the variety of materials and methods used. The increase in these materials' shear bond strength might be attributed to some differences in the properties of the materials tested. Differences in the chemical structure of Ivoclar teeth may explain this fact. Several studies demonstrated that the teeth's ridge-lap surface composition can affect the polymer tooth bonding to the denture base polymer.[2–4,7] Conventional acrylic resin teeth usually achieve a better bond to denture base resins, compared to highly cross-linked teeth.[15] The higher degree of cross-linking agents may restrict the availability of unlinked polymer chains to bond to the denture base and form a polymer network;[8,17] however, little information on the amount of cross-linking agents is provided by the manufacturers.

It is known that the ability of acrylic teeth to bond to denture base resins may also be affected by the type of denture base resin.[8] In the present study, Lucitone 550 denture base resin showed the highest mean shear bond strength value. This may be explained by the higher polymerization temperature of heat-polymerized resins, which enhances the diffusion of denture base polymer monomers into the acrylic resin polymer teeth.[2,15] Versyo.bond denture base resin also showed high shear bond strength values before and after thermocycling. This may be attributed to roughening of the ridge-lap surface of acrylic denture teeth. Some studies[14,22] have shown that roughening the ridge-lap surface of acrylic denture teeth increased the bond strength. Additionally, the application of a bonding agent to the ridge-lap surface of acrylic denture teeth might have improved the ability to bond to the acrylic teeth. Previous studies have shown that the application of adhesive bonding agents to acrylic teeth promoted an improvement in bond strength values.[4,14,15] Bonding agents increase the wettability of the tooth surface and may have a solvent effect, which favors a more effective diffusion of denture base polymer monomers into the tooth, reinforcing the bond between the denture base resin and the acrylic tooth;[20] however, special care should be taken when planning the use of light-polymerized acrylic resins in prosthodontic applications.[17] According to the manufacturer, the main indication of Versyo.bond resin is the fabrication of partial dentures, relines, and repairs, instead of larger appliances, such as complete dentures.

The intermediate bond strength values achieved by the microwave-polymerized acrylic resin Acron MC might have resulted from the difficulty in controlling the rising temperature of the exothermic polymerization reaction.[29] A rise in temperature above the monomer boiling point results in the formation of porosities.[30] Consequently, voids might have been formed at the acrylic denture tooth/denture base resin interface, contributing to the lower bond strength.[1] Additional studies, such

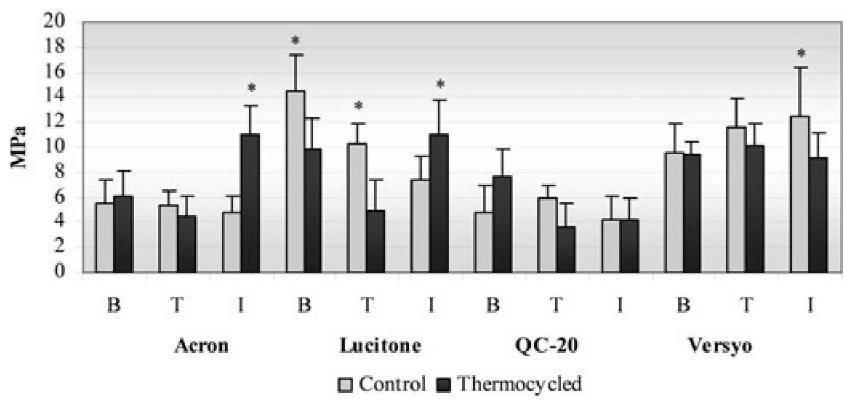

Figure 3 Shear bond strength of control and thermocycled groups of each denture base resin/acrylic tooth combination. *indicates significant difference ($p < 0.05$). The letters B, T, and I mean, respectively, Biotone, Trilux, and Ivoclar teeth.

Table 4 Mean shear bond strength values (MPa), standard deviations (SD), and 95% confidence interval of each group tested

	Control group (MPa)						Thermocycled group (MPa)				
	n	Min	Max	Mean	SD	C.I.	Min	Max	Mean	SD	C.I.
Acron/Biotone	10	2.48	8.15	5.55	1.89	1.2	3.67	9.33	6.12	1.98	1.2
Acron/Trilux	10	4.04	7.27	5.41	1.05	0.7	2.46	6.91	4.47	1.63	1.0
Acron/Ivoclar	10	3.31	7.22	4.84	1.30	0.8	7.44	14.09	11.01	2.31	1.4
Lucitone/Biotone	10	9.24	19.52	14.54	2.92	1.8	6.45	14.90	9.92	2.42	1.5
Lucitone/Trilux	10	7.67	12.23	10.26	1.57	1.0	2.46	10.95	4.89	2.55	1.6
Lucitone/Ivoclar	10	4.31	9.89	7.38	1.90	1.2	7.01	14.72	11.03	2.76	1.7
QC-20/Biotone	10	1.74	8.60	4.80	2.19	1.4	3.19	10.61	7.67	2.23	1.4
QC-20/Trilux	10	4.73	7.75	5.97	0.98	0.6	1.66	6.75	3.69	1.76	1.1
QC-20/Ivoclar	10	1.54	6.63	4.14	2.00	1.2	2.09	6.94	4.27	1.72	1.1
Versyo/Biotone	10	7.43	14.98	9.51	2.38	1.5	8.42	11.51	9.42	1.04	0.6
Versyo/Trilux	10	9.61	17.25	11.66	2.22	1.4	7.74	12.64	10.13	1.70	1.1
Versyo/Ivoclar	10	7.06	19.79	12.44	3.97	2.5	7.14	13.46	9.11	1.99	1.2

as a fractographic investigation, should be carried out in order to confirm this hypothesis.

The lowest bond strength values observed for the QC-20 denture base resin may be related to some features of this heat-polymerized acrylic resin. The liquid component of QC-20 contains a chemical activator (dimethyl-*para*-toluidine), which causes the decomposition of benzoyl peroxide; consequently, polymerization is initiated.[31] This process is similar to autopolymerizing acrylic resins. Thus, less time is available for the contact between tooth and denture base material before polymerization, as well as to dissolve part of the PMMA into the teeth surface to produce a satisfactory bond.[3,5]

It can be considered that the present study method and variables did not simulate all clinical conditions. Despite these limitations, the materials evaluated in this study are expected to perform similarly in the oral environment. Selecting more compatible denture base resin and acrylic tooth combinations must be taken into consideration to prevent debonding of acrylic teeth from the denture base.[22] Further studies are recommended to investigate other material combinations and to predict which materials would provide the best clinical service.

Conclusion

Within the limitations of this study and considering the materials tested, the following conclusions were drawn:

1. Thermocycling significantly decreased shear bond strengths of Lucitone 550/Biotone, Lucitone 550/Trilux, and Versyo.bond/Ivoclar specimens.
2. Shear bond strengths of Acron/Ivoclar and Lucitone/Ivoclar specimens significantly increased after thermocycling.
3. In general, the highest shear bond strength values were observed with Lucitone 550 and Versyo.bond acrylic resins and the lowest with QC-20.

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