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Strength of Denture Base Resins Repaired with Auto- and Visible Light-Polymerized Materials

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Keywords
Acrylic resin; impact strength; flexural strength; repair strength; repair methods.

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Accepted July 7, 2008

doi: 10.1111/j.1532-849X.2009.00470.x

Abstract

Purpose: Clinicians are still confused about the choice of repair method, which depends on factors such as the length of time required for processing, the mechanical strength of the repaired material, and the effect of stress concentration in the acrylic resins before the repair. The aim was to determine the impact and flexural strength characteristics, such as stress at yield, Young's modulus, and displacement at yield of denture base resins fractured and repaired by three methods using heat-, auto-, and visible light-polymerized acrylic resins.
Material and Methods: For impact and flexural strength tests, 18 rectangular specimens measuring $50 \times 6 \times 4$ mm^3 and $64 \times 10 \times 3.3$ mm^3, respectively, were processed using Impact 2000, Lucitone 550, Impact 1500, and QC-20 acrylic resins. Fracture tests were performed according to ISO1567:1999. Afterward, all fractured specimens were stored in distilled water at 37°C for 7 days, and then repaired with (1) the same acrylic resin used for specimen fabrication (n = 6), (2) an autopolymerized acrylic resin (TruRepair, n = 6), and (3) a visible light acrylic resin (Versyo.com, n = 6). The repaired specimens were again submitted to the same fracture tests, and the failures were classified as adhesive or cohesive. Data from all mechanical tests after repair by the different methods were submitted to two-way ANOVA, and mean values were compared by the Tukey test.
Results: All acrylic resins showed adhesive fractures after impact and flexural strength tests. Differences ($p < 0.05$) were found among repair methods for all acrylic resins studied, with the exception of displacement at yield, which showed similar values for repairs with auto- and visible light-polymerized acrylic resins. The highest values for impact strength, stress, and displacement at yield were obtained when the repair was made with the same resin the specimen was made of.
Conclusion: Denture base acrylic resins repaired with the same resin they were made of showed greater fracture strength.

Denture base fractures and cracks are complications related to removable prostheses, teeth, or implant-supported overdentures,[1-3] and fixed implant-supported prostheses,[4,5] resulting in great inconvenience to both patient and dentist. The most common problems are midline fractures and cracks at the posterior cantilever area, which can occur during function[6] as a result of fatigue failure.

Common measures to solve recurrent fractures and signs of cracks are temporary or definitive repairs,[7] which can be made using visible light-polymerized, autopolymerized, or heat-polymerized acrylic resins;[7-9] however, the choice of repair material still confuses clinicians. It depends on technical factors such as the length of time required for making the repair, the strength obtained with the material used to repair and the degree to which dimensional accuracy is maintained during the repair.[10] Also, the stress on the denture after years in clinical use[11-13] must be considered.

Heat-polymerized materials have been proved to have higher mechanical properties when compared with auto- and visible light-polymerized materials;[6,14-17] however, the laboratory packing and flasking procedures are time consuming and present risk of denture distortion by heat.[18]

Although repairs with auto- or visible light-polymerized materials have lower resistance, they are widely used clinically, due to being a faster procedure; however, there is no consensus about their mechanical properties. Repair strength of autopolymerized acrylic resin varies from 40% up to 90%,[1,8,19,20] while visible light-polymerized acrylic resin repair strength values range from 18% to 58% when compared to autopolymerizing acrylic resin.[6,15,17,21]

Therefore, as repair strength is far from ideal, mechanical or chemical surface modifications have been proposed, but most results show that only bond strength has been improved.[7,22-24] Thus, several resins with enhanced flexibility and high mechanical properties are currently available for prosthesis repair.[6,7] Among these are autopolymerized acrylic resins with low viscosity and the addition of cross-linking agents[10,16,23,24] and visible light-polymerized materials compatible with polymethylmethacrylate based on cross-linking organic matrix;[25,26] however, no reports were found related to these acrylic resins used as repair materials.

The purpose of this in vitro transversal study was to determine the impact strength and flexural characteristics of denture base resins fractured to simulate mechanical stress conditions and subsequently repaired with auto- and visible light-polymerized acrylic resins.

Material and methods

All acrylic resins used in this study are listed in Table 1.

Specimen preparation

Eighteen rectangular specimens measuring $50 \times 6 \times 4$ mm^3 and $64 \times 10 \times 3.3$ mm^3 were prepared using Lucitone 550, Impact 2000, Impact 1500, and QC-20 acrylic resins to be fractured by impact and flexural strength tests, respectively (Figs 1 and 2). Metal master patterns were individually invested with high-viscosity silicone (Zetalabor, Zermack S.p.A, Badia Polesine, Rovigo, Italy) and used to fabricate the specimens. Patterns were invested with type III dental stone (Herodent Soli Rock, Rio de Janeiro, Brazil) in metal dental flasks (Uraby, DLC, São Paulo, Brazil).[27] The acrylic resins were mixed in accordance with the manufacturers' instructions and packed into the silicone mold at the dough stage.

To polymerize Lucitone 550 and Impact 2000 acrylic resins, the flasks were placed in a polymerizing unit (Termotron P-100, Termotron Equipamentos Ltd, Piracicaba, Brazil) filled with water at 74°C for 9 hours. Flasks containing QC-20 and Impact 1500 were immersed in boiling water for 20 minutes. Afterward, all flasks were allowed to bench cool for 2 hours, then opened, and the specimens were finished using progressively

Table 1 Acrylic resins and products used in this study

Materials	Chemical composition	Polymerization method	Manufacturer/batch number
Lucitone 550	Powder: methyl methacrylate (methyl-n-butyl) co-polymer, benzoyl peroxide, mineral pigments Liquid: methyl methacrylate, ethylene glycol dimethacrylate,† hydroquinone	Water bath—9 hours at 73°C	Dentsply International, Inc., Chicago, IL/36898/37375
Impact 2000	Powder: nuisance dust, benzoyl peroxide, cadmium pigments Liquid: methyl methacrylate monomer, ethylene glycol†	Water bath—9 hours at 73°C	Bosworth Company, Skokie, IL /0401-022
Impact 1500	Powder: particulate NOC (noncadmium), residual monomer, titanium dioxide Liquid: methyl methacrylate monomer, alkyldimethacrylate†	Boiling water at 100°C for 20 minutes	Bosworth Company, Skokie, IL/0006-328
QC-20	Powder: methyl methacrylate (methyl-n-butyl) co-polymer, benzoyl peroxide, atoxic pigments Liquid: methyl methacrylate monomer, ethylene glycol dimethacrylate,† terpinolene, *N–N* dimethyl-p-toluidine, hydroquinone	Boiling water at 100°C for 20 minutes	Dentsply International, Inc., Chicago, IL/29080/60066
TruRepair	Powder: poly (methyl methacrylate), benzoyl peroxide, cadmium pigments Liquid: methyl methacrylate monomer, dimethyl-p-toluidine, alkyldimethacrylate†	At room temperature for 10 minutes	Bosworth Company, Skokie, IL/0108-474
Versyo.com	Cross-linked organic matrix, photo-hardening, single-component denture base resin consisting of dimethacrylate and multi-functional methacrylates	2 cycles of 90 seconds*; 1 cycle of 180 seconds**	Heraeus-Kulzer, Hanau, Germany/010109
Versyo.bond	Ethyl acetate, multifunctional and monofunctional methacrylates, acrylates, and photo-initiators	2 cycles for 90 seconds*	Heraeus-Kulzer, Hanau, Germany/010022-1

†Cross-linking agent; *Prepolymerization in the Heralight precuring unit; **Final polymerization in the UniXs.

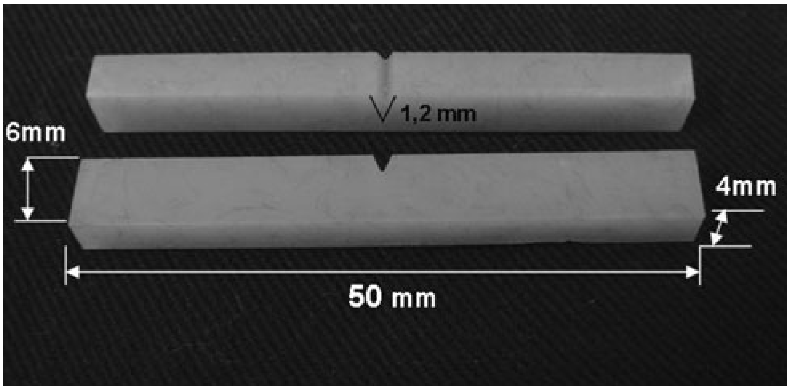

Figure 1 Intact specimen for the impact strength test.

smoother aluminum oxide papers (grit: 320, 400, 600) in a horizontal polisher (Arotec APL-4, Arotec, São Paulo, Brazil). After finishing procedures, the specimens were ultrasonically cleaned (Thornton T 740, Thornton-Inpec Eletrônica Ltda, Vinhedo, Brazil) for 20 minutes and then immersed in distilled water at 37°C for 48 ± 2 hours. To simulate fractured prostheses and their defects as a result of plastic deformation, the specimens were submitted to fracture tests and were subsequently repaired.

Impact strength test

The impact strength test was performed according to ISO standard 1567:1999/Amd.1:2003(E),[28] using an impact test machine (AIC, EMIC, São José dos Pinhais, Brazil) by the Charpy method with a pendulum of 0.5 J, in which the specimens were horizontally positioned with a distance of 40 mm between the two fixed supports.

Flexural strength test

Flexural characteristics such as the stress at yield, Young's modulus, and displacement at yield of intact and repaired specimens were determined by the three-point bending test using a universal testing machine (Instron Model 4467, Instron Industrial Products, Grove City, PA) calibrated with a 500 kgf load cell and a crosshead speed of 5 mm/min.

The flexural testing device consisted of a central loading plunger and two polished cylindrical supports, 3.2 mm in diameter and 10.5 mm long. The distance between the centers of the supports was 50 mm. The compressive force was applied perpendicular to the center of the intact specimens and at the midline of the repaired material, until a deviation of the load-deflection curve and fracture of the specimen occurred.

Repair procedures

After impact and flexural strength tests, the fractured specimens were randomly divided into three groups to be repaired using: (G1) the same acrylic resin as was used to fabricate the specimen (control); (G2) an autopolymerizing MMA-based acrylic resin (TruRepair, Bosworth Company, Skokie, IL), and (G3) a visible light-polymerized acrylic resin (Versyo.com, Heraeus-Kulzer, Hanau, Germany).

The butt joint surface design was chosen[29] for all repair methods, and the cross-section of each half of a fractured specimen was polished with pumice powder and ultrasonically cleaned. The paired halves were then put back into the same preparation silicone mold, keeping a 3 mm gap between the edges of each half of the specimen.

The joint surfaces of specimens in G1 and G2 were first treated with the monomer liquid of each acrylic resin for 3 minutes, and the gap was filled with acrylic resin. The heat-polymerized acrylic resins were then processed as previously described, while the autopolymerized acrylic resin (TruRepair) was considered polymerized when it had lost its glaze (10 minutes).

The joint surface of G3 was first coated with bonding agent (Versyo.bond, Heraeus-Kulzer) for 60 seconds and polymerized for two cycles of 90 seconds in the Heralight precuring unit (Heraeus-Kulzer). Next, the visible light-polymerized acrylic resin was carefully packed into the gap through two increments prepolymerized for 60-second cycles. The final polymerization was processed in the UniXS curing box (Heraeus-Kulzer) for 3 minutes.

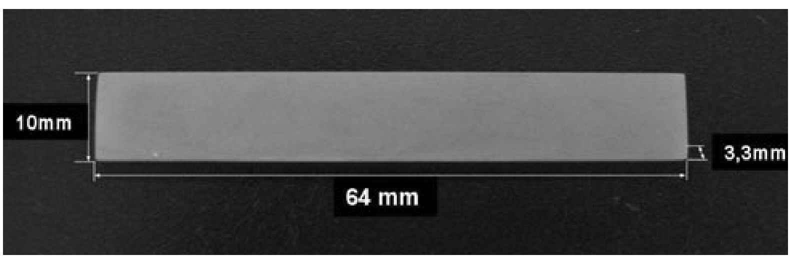

Figure 2 Intact specimen for the flexural strength test.

Table 2 Two-way ANOVA comparison for impact strength, stress at yield, Young's modulus, and displacement at yield values after repair procedures

Mechanical tests	Source of variation	Degree of freedom	Sum of square	Mean square	*f*-test	*p*-value
Impact strength	Acrylic resin	3	0.506	0.169	22.490	<0.001
	Repair method	2	2.696	1.348	179.780	<0.001
	Resin × Repair method	6	0.913	0.152	20.290	<0.001
	Residual	60	0.45	0.008		
	Total	71	4,565	0.064		
Stress at yield	Acrylic resin	3	0.079	0.026	1.950	0.1318
	Repair method	2	1.553	0.776	57.160	<0.001
	Resin × Repair method	6	0.197	0.033	2.420	0.0369
	Residual	59	0.801	0.014		
	Total	70	2.630	0.037		
Young modulus	Acrylic resin	3	0.459	0.153	137.140	<0.001
	Repair method	2	0.010	0.005	4.670	0.013
	Resin × Repair method	6	0.016	0.003	2.350	0.0422
	Residual	60	0.067	0.001		
	Total	71	0.552	0.008		
Displacement at yield	Acrylic resin	3	1.515	0.505	9.700	<0.001
	Repair method	2	7.891	3.945	75.780	<0.001
	Resin × Repair method	6	0.498	0.083	1.590	0.1649
	Residual	59	3.072	0.052		
	Total	70	12.98	0.186		

After polymerization, the surfaces of each repaired specimen were finished and polished using a polishing machine (Arotec APL-4) and 600-grit sandpaper (Carbimet, Buehler, Lake Bluff, IL). All repaired specimens were stored in distilled water at 37°C for 7 days and evaluated for impact and flexural strength as previously described.

Fractures of specimens were classified as adhesive or cohesive.

Statistical analysis

Statistical analysis was done using SAS software (SAS Institute, Inc., version 8.01, Cary, NC) with a significance level fixed at $p < 0.05$. ANOVA was used to test the null hypothesis of no difference among the repair methods or acrylic resins. The assumptions of equality of variances and normal distribution of errors were checked for each variable, and when violated, the data were transformed.[30] As mean values were not normally distributed, the impact strength and stress at yield data were transformed by exponentiation, Young's modulus data by log10(X), and displacement at yield data by square root. The Tukey test was then used for post-ANOVA comparisons.

Results

All acrylic resin fractures from impact and flexural tests were classified as adhesive.

The two-way ANOVA results for impact strength, stress at yield, Young's modulus, and displacement at yield after repair methods are presented in Table 2. The mean values comparison and standard deviations for impact strength, stress at yield, Young's modulus, and displacement at yield after repair are described in Table 3.

With respect to impact strength, when the repair methods were compared for each acrylic resin, Lucitone 550 and Impact 2000 showed statistical differences among all repair procedures ($p < 0.05$) and higher values when repaired with the same resin they were made of. Impact 1500 only showed statistical differences and presented lower value ($p < 0.05$) when repaired with visible light-polymerized acrylic resin. QC-20 acrylic resin showed an increased value ($p < 0.05$) when repaired with the same resin.

Analyses of the behavior of each acrylic resin studied, when submitted to flexural strength testing, pointed out that they differed according to the repair method used.

Regarding stress at yield, repairs made with the same resin that the specimen was made of showed higher and statistically significant values ($p < 0.05$), except for QC-20 resin; this acrylic resin did not present any differences when repaired with either auto- or visible light-polymerized resin, but QC-20 showed similar results when repaired with the same resin the specimen was made of and autopolymerized resin.

Young's modulus data showed that repair methods were different only for Lucitone 550 repaired with autopolymerized acrylic resin, which obtained lower values than the same resin and visible light-polymerized acrylic resin ($p < 0.05$). On the other hand, with regard to displacement at yield, the best performance was reached with the repair made of the same resin used for fabricating the specimens ($p < 0.05$).

Discussion

Denture fracture is still a problem for patients and dentists. In this study, the repair methods were performed using two halves

Table 3 Mean values and standard deviations for impact strength, stress at yield (MPa), Young's modulus (MPa), and displacement at yield (mm) after repair methods ($n = 6$)

Mechanical tests	Acrylic resin	Acrylic resins used for repair		
		Same resin	Autopolymerized	Visible light
Impact strength	Lucitone 550	3.3 ± 0.6 (a)	1.5 ± 0.3 (b)	0.8 ± 0.2 (c)
	Impact 2000	3.2 ± 0.3 (a)	1.2 ± 0.3 (b)	1.9 ± 0.5 (c)
	Impact 1500	1.8 ± 0.5 (a)	1.6 ± 0.4 (a)	0.5 ± 0.0 (b)
	QC-20	3.0 ± 0.6 (a)	1.0 ± 0.0 (b)	1.0 ± 0.0 (b)
Stress at yield	Lucitone 550	48.3 ± 13.5 (a)	19.0 ± 3.1 (b)	20.3 ± 8.5 (b)
	Impact 2000	47.9 ± 20.8 (a)	20.5 ± 5.3 (b)	23.5 ± 4.4 (b)
	Impact 1500	38.6 ± 5.4 (a)	19.7 ± 8.8 (b)	18.6 ± 2.5 (b)
	QC-20	31.5 ± 4.8 (a)	25.0 ± 3.6 (a,b)	18.9 ± 6.0 (b)
Young's modulus	Lucitone 550	2239 ± 65 (a)	1981 ± 111 (b)	2158 ± 238 (a,b)
	Impact 2000	1899 ± 146 (a)	1926 ± 186 (a)	2126 ± 232 (a)
	Impact 1500	1495 ± 132 (a)	1572 ± 62 (a)	1646 ± 99 (a)
	QC-20	1278 ± 83 (a)	1364 ± 91 (a)	1373 ± 94 (a)
Displacement at yield	Lucitone 550	3.2 ± 0.7 (a)	1.6 ± 0.2 (b)	1.3 ± 0.7 (b)
	Impact 2000	3.6 ± 1.5 (a)	1.7 ± 0.5 (b)	1.9 ± 0.5 (b)
	Impact 1500	4.8 ± 1.1 (a)	2.0 ± 0.7 (b)	1.8 ± 0.3 (b)
	QC-20	5.0 ± 1.2 (a)	3.2 ± 1.1 (b)	1.8 ± 0.8 (b)

Different letters show significant differences among repair methods for acrylic resin ($p < 0.05$).

of an already fractured specimen, considering maintenance of stress and crack propagation.

The results showed that fractured specimens repaired with the same acrylic resin they were made of reached higher strength, except for Impact 1500, which showed higher values for impact strength when repaired with itself or by using the autopolymerized acrylic resin method. These results could be attributed to the treatment of the fractured surface with the monomer, considering that Impact 1500 and autopolymerized acrylic resin have the same cross-linking agent (alkyl dimethacrylate) in their composition; this could result in a greater affinity of monomers in the formation of the new polymeric chains.[9,31]

The effects of using visible light-polymerized acrylic resin on the impact strength of the repaired acrylic resins was more evident in the Impact 1500 and Lucitone 550 resins, which showed a decrease of 75.8% and 72.3%, respectively, when compared with those repaired with the acrylic resin they were made of (Table 3). These decreased values can be explained by the differences in the composition of the resins related to (1) the cross-linking agents with different types and concentrations, (2) the bond agent with different compositions, and (3) the filler content (as titanium dioxide, in Impact 1500 composition). These substances could reduce the bond agent penetration into the polymeric matrix, resulting in poor interaction and lack of adhesion and/or cohesion between the materials.[17,32-34]

Regarding the stress at yield, comparisons among repair methods showed that specimens repaired with the same acrylic resin they are made of exhibited higher values ($p < 0.05$), as expected (Table 3). These findings differ from some studies,[8,12,19,35,36] and a possible explanation could be the differences in the methodologies used. Moreover, in this study, repaired specimens previously fractured by mechanical tests were evaluated, instead of using specimens first sectioned in the middle, as made by other authors.[6-8,11,12,15,29] Therefore, it can be considered that the design of our study simulated the clinical procedure in which prostheses are repaired maintaining their plastic deformation and stress.

Although the stress at yield values were higher for Lucitone 550 and for Impact 2000 repaired with the same resin (Table 3), they underwent a significant reduction in the strength: 47% and 50%, respectively. These findings could be attributed to stress concentration from packing, flasking, and heating procedures[8] as a result of the second polymerization. Stress absorption decreased by 30% in the Impact 1500 resin, but QC-20 was not affected by the repair method.

The results of our study also indicated that repairs did not influence the rigidity of the denture base materials, as Young's modulus values did not differ among the repair methods (Table 3). Probably, this property was not affected by the plastic or the elastic stress intensity induced in the materials.[37]

In the present study, as no interaction between acrylic resins and repair methods was found for the displacement at yield, the lack of adhesion could be attributed to either the small area provided by the butt joint, or to the maintenance of plastic deformation, or even to the different chemical composition of the resins used for repair, which usually results in different flexural characteristics. In addition, differences were seen among the repair methods, with the higher values for repairing with the same resin that the specimen was made of ($p < 0.05$). In contrast, when auto- or visible light-polymerized acrylic resin methods were used, the values decreased by almost 50%. This can be clarified by the chemical composition of the resins and the capacity of stress absorption.[7,11,13,23]

The adhesive failures originated by the two mechanical tests could be attributed to the butt joint.[3,23,26] Several factors have been described as capable of affecting the strength of the repaired acrylic resin, such as the contour of the butt joint surface,[10,29] pretreatment of the surfaces with monomer,[38] and longer water storage periods.[6,39] The butt joint was chosen because it requires less preparation and a joint area that is more homogeneous than 45° bevel joint, round joint, or edge joint.[9,14,29]

In this study, denture base resins, polymerization cycles, and repair protocols differed among the three repair methods studied. Thus, the choice of combining the repair method and denture base acrylic resin is of major importance to obtain the best mechanical properties and bond strength. The limitations of this study are the fact that the mechanical tests have not been performed in wet conditions similar to the oral cavity and that no one form of aging has been used.

Conclusion

Within the limitations of this study, denture base resin repaired with the same resin used to fabricate it showed greater flexural and impact strength. Thus, this procedure should be considered by clinicians when repairing fractured dentures.

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