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Fracture Force, Deflection, and Toughness of Acrylic Denture Repairs Involving Glass Fiber Reinforcement

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Abstract

Purpose: Fractures in acrylic resin dentures occur quite often in the practice of prosthodontics. A durable repairing system for denture base fracture is desired to avoid recurrent fracture. The purpose of this study was to evaluate the fracture force, deflection, and toughness of a heat-polymerized denture base resin repaired with autopolymerized resin alone (C), visible light-polymerizing resin (VLC), or autopolymerizing resin reinforced with unidirectional (Stick) (MA-FS) and woven glass fibers (StickNet) (MA-SN). Another group was repaired with autopolymerized resin after wetting the repair site with methyl methacrylate (MA-MMA) for 180 seconds. A group of intact specimens was used as control.
Materials and Methods: Heat-polymerizing acrylic resin was used to fabricate the specimens. The specimens (10 per group) were sectioned in half, reassembled with a 3-mm butt-joint gap, and repaired. A cavity was included when glass fibers were used. Three-point bending was used to test the repaired site, and data were analyzed with one-way ANOVA and the Tukey's post hoc test ($\alpha \leq 0.05$).
Results: Fracture force, deflection, and toughness for the repaired groups without reinforcement (MA: 46.7 ± 8.6 N, 2.6 ± 0.3 mm, 0.08 ± 0.001 J; MA-MMA: 41.0 ± 7.2 N, 2.7 ± 0.4 mm, 0.07 ± 0.002 J) were significantly lower ($p < 0.05$) than the control group (C: 78.6 ± 9.6 N, 5.9 ± 0.4 mm, 0.27 ± 0.003 J). Repair with visible light-polymerizing resin (VLC, 15.0 ± 4.0 N, 1.2 ± 0.4 mm, 0.02 ± 0.0001 J) resulted in significant reduction of mechanical properties ($p < 0.05$). Reinforcement with glass fibers restored (MA-SN: 75.8 ± 9.2 N) or increased (MA-FS: 124.4 ± 12.5 N) the original strength.
Conclusion: The most effective repair method was the use of autopolymerized resin reinforced with unidirectional glass fibers.

Heat-polymerizing acrylic resin, since its introduction several decades ago, has been the material of choice for the construction of denture bases for numerous reasons.[1] Yet it is associated with two important clinical disadvantages: low flexure fatigue and impact resistance.[2] Fractures in acrylic dentures result from impact or bending forces. Impact forces typically are created during an accidental fall into a washbasin or onto the floor. Bending forces are developed mainly during mastication because of poor adaptation of the denture to the underlying mucosa, improper occlusion, morphology of the palate, excessive masticatory forces, or denture deformation during use. Those bending forces in long-term contribute to fatigue of the material.[3,4]

The ultimate goal of denture repair is to restore or reinforce the denture's strength in order to avoid recurrent fractures. Target values of heat-polymerized denture resin are reported in the original ISO standard (1567:1988[1]) for transverse fracture force as not less than 55 N. In the newest ISO standard (1567:1999[5]), the flexural strength and modulus are targeted to be not less than 65 and 2000 MPa, respectively. At the same time, the repair procedure has to be rapid, easy to perform, inexpensive, not change the original color, and preserve the dimensions of the denture. Several materials have been used to repair fractured acrylic resin, including autopolymerized acrylic resin and visible light-polymerized resin. Autopolymerized resin is the repair material most commonly employed.[6] Unfortunately, its strength has been shown to range from 18 to 81% of intact heat-polymerized denture resin.[7–17] Repairs with visible light-polymerized resin result in even lower final strengths.[12,18–20]

Several methods have been used to reinforce the denture repair and avoid recurrent fractures, including metal strengthening or reinforcing fibers, but the results of those attempts is limited. Kouno et al[21] assessed the breaking strength of denture bases repaired with Co-Cr alloy reinforcement wires or San-cobalt palatal bars. They concluded that although the breaking strengths of the denture bases were reduced by the repair, greater strengths were achieved using the thicker palatal bars. Polyzois et al[16] examined the strength of heat-polymerized acrylic resin strips and denture bases repaired with Meta Fast autopolymerizing adhesive resin alone or in combination with metal wires. The results indicated that certain types of metal wires considerably enhanced the repair of one kind of denture acrylic resin. Vallittu[22] conducted a pilot clinical study (1–3 years) in which 22 complete and partial acrylic dentures were repaired with silanized glass fibers. From the results of the study it was concluded that glass fibers incorporated into fractured removable prostheses strengthened the acrylic resin and prevented future fracture. The pilot study was expanded to cover 51 acrylic dentures for a follow-up time of 4.1 years. In 88% of the cases, there was no need for adjustments at the region of glass fiber reinforcement.[23] Nagai et al[24] reported that the reinforcement of repaired acrylic denture with glass fiber and methylene chloride pretreatment produced a transverse strength and a modulus of elasticity that were higher than the control.

The purpose of this study was to evaluate the fracture force, deflection, and toughness of a heat-polymerized denture base resin repaired with autopolymerized resin alone, visible light-polymerizing resin, or reinforced with unidirectional (Stick) and woven glass fibers (StickNet). Another group was repaired with autopolymerized resin after wetting the repair site with methyl methacrylate for 180 seconds.

Materials and methods

Specimen preparation

The materials used in this study are listed in Table 1. Meliodent heat-polymerizing denture base resin was used to prepare the test specimens. The mixing ratio of heat-polymerized resin was 23.4 g powder to 10 mL monomer, and the mixing time was 40 seconds. After 6 minutes from the start of mix, the material reached the dough stage for packing into the moulds. Polymerization took place in a dry heat oven at 75°C for 12 hours. Blocks of Meliodent heat-polymerized resin were produced by investing wax pattern blocks, each measuring 3 × 60 × 65 mm (±0.05 mm), in dental stone using metal flasks. After dewaxing at 100°C for 5 minutes, the heat-polymerized resin was packed. After deflasking, individual specimens measuring 3 × 10 × 65 mm were cut from the blocks using a band saw. The specimens were hand-finished using a 600-grit silicon carbide paper and a polishing machine to the final dimensions of 2.5 × 10 × 65 mm (±0.05 mm). A total of 60 Meliodent specimens were prepared and stored in a water bath for 28 days to attain saturation. The specimens were divided into six groups according to the repair method; each group comprised 10 specimens (Table 2).

Specimen preparation for repair

After 28 days of storage in water bath, 50 specimens were cut in the middle with a band saw. Ten specimens remained intact and served as the control group. The cut surfaces were ground to a butt profile and finished by rubbing with wet 240-grit silicon carbide paper. Additionally, a 3.5 × 65 mm central channel, which would be repaired with glass fiber reinforcement, was created in 20 specimens.

Repair of specimens

Meliodent autopolymerized repair resin and Microbase VLC repair resin were used to repair the denture resin. Groups of specimens and methods of repair are presented in Table 2. The mixing ratio of Meliodent autopolymerized resin was 5 g powder to 3.5 g liquid. Polymerization took place in a pressure pot containing water at 55°C and 2 bars pressure for 15 minutes. The VLC resin was distributed in syringes and was cured in a Triad 2000 curing unit (Dentsply, DeTrey GmbH, Kunstanz, Germany) for 10 minutes.

Repaired denture surfaces were not treated, except in one group of autopolymerized resin without reinforcement where the butt joints were treated with methyl methacrylate for 180 seconds.

Table 1 Materials used

Name	Manufacturer	Batch number
Meliodent heat-polymerized	Heraus Kulzer Ltd, Newbury, UK	#46405W-1 powder #46382-W liquid
Meliodent autopolymerized	Heraus Kulzer Ltd, Newbury, UK	#54497 B-5/2 powder #54649-B liquid
Microbase VLC	Dentsply, DeTrey GmbH, Kunstanz, Germany	#F 135120
Stick	Stick Tech Ltd, Turku, Finland	#2010907-R-0059
Stick Net	Stick Tech Ltd, Turku, Finland	#1990304-W-0032

Table 2 Test groups for repairing acrylic denture materials

Group abbreviation	Repair method
C	Intact heat-cured specimens (control group)
MA	Repaired with Meliodent autopolymerized acrylic resin
MA-FS	Repaired with Meliodent autopolymerized acrylic resin reinforced with glass fibers (Stick)
MA-SN	Repaired with Meliodent autopolymerized acrylic resin reinforced with StickNet
MA-MMA	Wetting of the repaired surface with methyl methacrylate for 180 sec and repair with Meliodent autopolymerized acrylic resin
VLC	Repaired with Microbase VLC resin

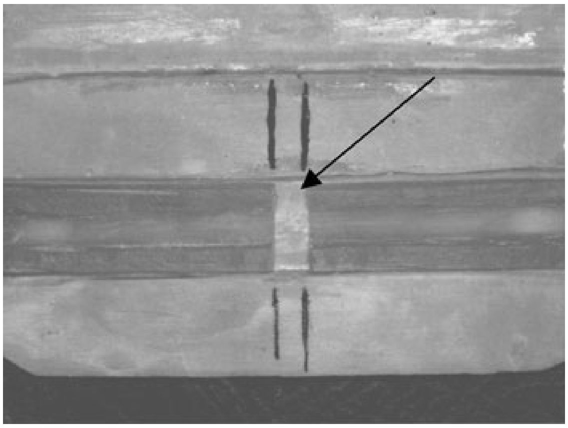

Figure 1 Split acrylic resin bar with 3 mm of space reserved for acrylic resin repair (see arrow).

Prepared halves of specimens were placed in open-ended molds with the same dimensions as the original control specimens, so the ends to be repaired could be moved apart to create a 3-mm gap (Fig 1). A free-flowing mixture of denture resin was introduced into the central recess and butt joint. A slight excess was included to compensate for polymerization shrinkage. Glass-fiber reinforcement was applied in the form of unidirectional monolayer glass fibers (Stick) or thin glass-fiber fabric (StickNet). Prior to their placement in the mixture of the repair resin, fibers were wetted with a powder-liquid mixture of very low viscosity for at least 2 minutes (Stick) or 10 minutes (StickNet) according to the manufacturer's directions for use. The fiber reinforcement was placed simultaneously with the placement of the mixture of resin.

Testing procedure

After the repair, all specimens were carefully restored to their original dimensions by polishing with 600-grit silicon carbide paper. Test specimens were stored in distilled water at 37°C for 48 hours before testing. Three-point bending tests were carried out in air at 21 ± 1°C using an Instron universal testing machine (Model 6022, Instron Corp., Canton, MA) operating at a crosshead speed of 5 mm/min with a span of 50 mm. Specimens were set wet from the storage container directly onto the testing apparatus. Load-deflection curves, fracture force, deflection, and energy were calculated automatically and displayed by the computer software of the testing machine (Fig 2). Toughness is related to the area under the load-deflection curve and represents the energy absorption needed to break a specimen. Energy was calculated as the integral of the area under the load-deflection curve and reported in units of Joules (N-m) Statistical analysis of the results used one-way analysis of variance (ANOVA) and the Tukey's post-hoc analysis ($a \leq 0.05$) with Minitab Statistical Software (Release 8, Minitab, Inc., State College, PA).

Results

Mean values, standard deviations, and statistical results for all measurements are reported in Table 3. The specimens repaired with autopolymerized resin reinforced with glass fibers Stick (MA-FS group) showed a fracture force greater than that of the control specimens ($p \leq 0.05$). The specimens repaired with autopolymerized resin reinforced with glass fibers StickNet (MA-SN group) restored (96%) the original strength with no statistical difference from the control group ($p > 0.05$). Repair with autopolymerized resin alone (MA group) showed a 41% decrease in fracture force compared with the control group. Repair with autopolymerized resin (MA-MMA group) presented a 37% decrease in fracture force, but the difference from the MA group was not statistically significant. VLC repair resin presented very poor repair characteristics, as it showed an 81% decrease in fracture force.

Concerning the deflection at fracture, the MA-FS group nearly restored (98%) the original deflection at fracture of the control group with no statistical difference between the two groups ($p > 0.05$). All other groups of specimens showed significantly lower deflection at fracture compared with the control group ($p > 0.05$). The MA-SN repaired specimens presented a 36% lower deflection at fracture compared with the control group, while the decreases for the MA and the MA-MMA group (57% and 54%) were significantly greater with no statistical difference between those two groups. VLC repair resin showed the greatest decrease (79%) of deflection at fracture.

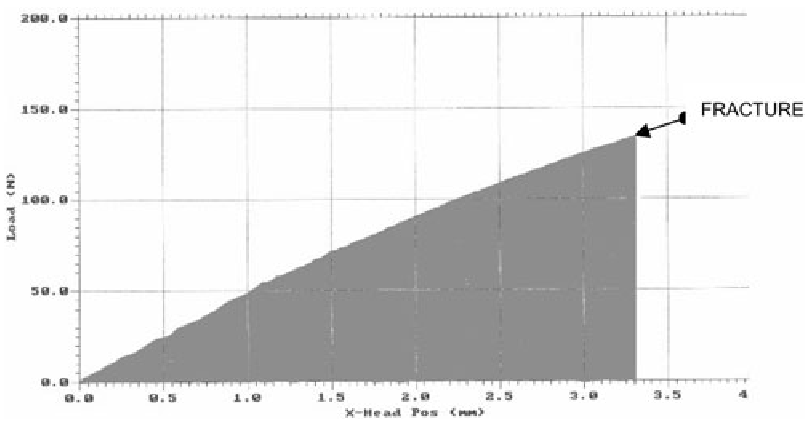

Figure 2 Load-deflection curve from mechanical testing with the area under the curve representing toughness.

Table 3 Mechanical test results for fracture force, deflection at fracture, and toughness for repaired denture specimens

Group	Fracture force (N)	Deflection (mm)	Toughness (J)
C	78.6 ± 9.6[a]	5.9 ± 0.4[c]	0.27 ± 0.003[c]
MA	46.7 ± 8.6[b]	2.6 ± 0.3[d]	0.08 ± 0.001[e]
MA-FS	124.4 ± 12.5[c]	5.8 ± 0.4[c]	0.56 ± 0.007[d]
MA-SN	75.8 ± 9.2[a]	3.8 ± 0.4[b]	0.16 ± 0.003[b]
MA-MMA	41.0 ± 7.2[b]	2.7 ± 0.4[d]	0.07 ± 0.002[e]
VLC	15.0 ± 4.0[d]	1.2 ± 0.4[a]	0.02 ± 0.0001[a]

Mean ± SD; means with the same superscript letters within columns are not statistically different ($p > 0.05$).

The results for the toughness showed that the specimens of the MA-FS group required significantly more energy absorption to break (107% increase) compared with the control group ($p < 0.05$). The reinforcement of the repair with StickNet (MA-SN group) showed a 39% lower toughness than the control group. Repair with autopolymerized resin alone resulted in a 71% decrease in toughness. Wetting of the repair surface with methyl methacrylate for 180 seconds prior to the repair resulted in a slight increase in toughness compared with the MA group, but it was not significantly different. VLC repair resin resulted in a 95% decrease in toughness. All repaired specimens fractured in an adhesive mode, meaning that the failure occurred between the parent and the repaired resin.

Discussion

In a survey of denture repairs, autopolymerized acrylic resin was the most preferred (86%) material for denture repair.[6] Results from previous studies have shown that the strength of autopolymerized resin repair is only 18 to 81% that of intact heat-polymerized denture resin. Consequently, recurrent fractures are a very common phenomenon. The relatively low strength of autopolymerized resin repair was confirmed by the results of the current study. The MA group was restored to only 59% of fracture force compared to the control group, while the deflection at fracture and toughness were significantly lower compared with the control group. Wetting of the repair surface with methyl methacrylate for 180 seconds and repair with autopolymerized resin (MA-MMA group) did not significantly affect any of the mechanical properties tested compared with the MA group. Vallittu et al[25] reported that a proper wetting of the repair surface with methyl methacrylate dissolves the surface structure of PMMA and improves the bond with the autopolymerized resin; however, the solubility of heat-polymerized PMMA [poly(methyl methacrylate)] is affected by some additives, such as copolymers, that are incorporated into the PMMA powder.[25] Thus, varying PMMA solubility may explain the difference in results.

Repair with VLC resin resulted in very poor mechanical properties. This may be due to a combination of factors, such as poor wettability of repair joint by the VLC resin, its higher viscosity, reduced flow rate, and higher stiffness compared to autopolymerized acrylic resin.[18–20] Findings in the current study revealed a significant decrease in all mechanical properties tested compared with all other groups, which is in agreement with previous studies.[12,18–20]

Glass fiber reinforcement of the repair site has been reported to affect mechanical properties;[17,24] however, the mechanical properties of any fiber composite depend on the direction of the fibers in the polymer matrix. The reinforcing effect of unidirectional fibers is only in one direction (anisotropic), whereas randomly oriented fibers tend to reinforce in all directions, and the mechanical properties are isotropic. This study revealed different reinforcing effects of unidirectional glass fibers (Stick) compared to thin fiberglass fabric (StickNet). Reinforcement with glass fibers (Stick) (MA-FS group) significantly increased the fracture force and toughness while not affecting the deflection at fracture compared with the intact specimens (control group). This effect may derive from the polymer preimpregnation for this fiber reinforcement system. After wetting of fibers with a mixture of polymer powder and monomer liquid instead of simply plain monomer, the potential for excess of monomer remaining inside the fiber reinforcement is avoided, and after polymerization the product has a dense fiber composite structure. The reinforcing effect of StickNet (MA-SN group) was minor, and while it restored the original fracture force of the intact specimens, the deflection at fracture and the toughness were significantly lower. This finding is in agreement with the theoretical efficiency predicted for reinforcement (the Krenchel's factor), which is 100% for unidirectional fibers and 50 to 25% for woven fibers.[26] It corroborates the results of Polyzois et al,[17] who tested the same auto- and heat-polymerizing acrylic resins with a different brand of monolayer glass fiber fabric. Also, the current results are consistent with those of Nagai et al,[24] who used a multilayer glass fiber fabric and treated the repair site with methylene chloride.

Material fatigue is the predominant failure mechanism of dental appliances, and for this reason the importance of carrying out dynamic fatigue studies in water or artificial saliva of denture repairs with or without fiber reinforcement must be emphasized. The findings of this current in vitro study demonstrate that preimpregnated unidirectional glass fibers enhance fracture resistance (i.e., fracture load, toughness of acrylic denture repairs). It also must be noted that in vitro studies are limited in their ability to predict the success of a material or procedure in a clinical environment. Moreover, future clinical trials would be very helpful to evaluate usefulness and durability of glass-fiber reinforcement in repair of removable dentures.

Conclusions

Within the limitation of this study, the following conclusions were drawn:

1. The fracture force, deflection at fracture, and toughness for all repaired groups without reinforcement (MA, MA-MMA, VLC) were significantly lower ($p < 0.05$) than those of the control group.
2. The group reinforced with StickNet (MA-SN) nearly restored the original strength, but presented significantly lower deflection at fracture and toughness ($p < 0.05$).
3. The group reinforced with unidirectional glass fibers Stick (MA-FS) presented significantly increased fracture force and toughness, while the deflection at fracture was similar to that of the control group ($p < 0.05$).

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