Effects of different glass fibers on the transverse strength and elastic modulus of repairing acrylic resin

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ABSTRACT
Objectives: The aim of this study was to evaluate the transverse strength and the elastic modulus of a heat-polymerized denture base resin repaired by adding various glass fibers into an autopolymerizing acrylic resin.
Background: The key problems frequently encountered in dentures are fractures. A durable repairing system for a denture base fracture is desired to avoid recurrent fracturing.
Materials and Methods: Fifty rectangular (65 mm × 10 mm × 2.5 mm) heat polymerized resin specimens were prepared which were divided in to five groups, with each including ten specimens. For the repairing procedure, samples with the autopolymerizing resin reinforced with stick, woven and chopped glass fibers were prepared. In addition, control samples with the autopolymerizing resin alone (in the absence of the glass fibres) were also obtained. Three-point bending tests were performed on all specimens.
Results: The mean transverse strength for the control samples was 78.93 MPa. The specimens repaired with stick fiber reinforced resin exhibited the highest mean transverse strength of 83.16 MPa. The mean elastic modulus of the control specimens was 2121.86 MPa. The mean elastic modulus of the stick group was 7420 MPa. The elastic modulus values of the stick fiber reinforced specimens were significantly higher than the other groups ($p < .05$).
Conclusions: Amongst all samples, the transverse strength and elastic modulus of the stick fiber reinforced samples was found to be the highest.
Keywords: Acrylic repair, elastic modulus, glass fiber reinforcement, transverse strength.

INTRODUCTION

The need for the prosthetic treatment has been more often objective than subjective. While clinical protocols of denture quality determination recommend treatment, most long time denture-users remain symptomatically unaware of the need and hence, are reluctant to replace the dentures. Therefore, instead of treating elderly people routinely by simply replacing their reasonably tolerated and accepted old dentures, it would in most cases be preferable to repair and readjust the old dentures for further use. This would lower costs and eliminate problems encountered by elderly people with regard to adapting to new complete dentures.[1]

Polymethylmethacrylate, with its favorable physical and aesthetic properties as well as ready availability, reasonable cost, and ease of manipulation, is a commonly used denture base material.[2,3]

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However, heat-polymerizing acrylic resin is associated with two important clinical disadvantages, i.e., low flexure fatigue and impact resistance.[4] Denture fractures are frequently encountered, requiring clinical assistance.[5] Until improvements yielding a tougher denture base material are made, acrylic resin fractures in removable prostheses are unavoidable.

The ultimate goal of denture repair is to attain the original shape and strength of the denture with minimum cost and time investment.

Several techniques and materials have been used to repair fractured dentures. Fractured acrylic resin dentures are repaired with autopolymerizing acrylic resin,[6-8] heat-curing acrylic resin, microwave-polymerized acrylic resin,[9] and more recently, visible light-cured resins have been used.[6]

Although various methods have been proposed for repairing fractured denture bases, the use of autopolymerizing acrylic resin, which generally allows for a simple, quick, and economic repair, is the most popularly chosen method.[10-12] Unfortunately, the repaired units appear to lose 40% to 60% of their original transverse strength.[5,10,13] Dentures repaired with autopolymerizing acrylic resin alone often experience a re-fracture at the repaired site.[12,14] One of the reasons for this unfavorable phenomenon is the insufficient transverse strength of the autopolymerizing acrylic resin, which is lower than that of a heat-polymerizing acrylic resin.[14] Comparing the different repair techniques, repairs made with autopolymerized acrylic resins exhibit the lowest flexural strength values.[9,15]

One way of repairing systems with acrylic resin fractures is the combined use of the autopolymerizing acrylic resin with reinforcing materials like glass fibers.[7] Glass fibers were shown to be most suitable for dental applications because of good cosmetic qualities[2,4,7,16] and good bonding to the polymer matrix via silane coupling agents.[17,18] Various studies reported that glass fibers had increased the transverse strength,[2,19-22] elastic modulus,[2,4,22] and impact strength[3,4,19] of acrylic resins. The use of glass fibers in repairing removable dentures had been reported to yield successful results.[7,13]

The purpose of this study was to investigate the efficacy of various types of glass fibers for denture base repairing.

MATERIALS AND METHODS

Specimen preparation

Impact samples were prepared from heat-polymerized denture base acrylic resin (Paladent, Heraeus Kulzer GmbH, Wehrheim, Germany). For the repairing procedure, autopolymerizing acrylic resin (Panacryl, Arma Dental Tibbi Malzeme San. ve Tic. Ltd. Sti, Istanbul, Turkiye) was used. For reinforcement, stick glass fibers (Ever Stick Crown and Bridge, Stick Tech Ltd, Turku, Finland), woven glass fibers (StickNet, Stick Tech Ltd, Turku, Finland) and silanized (γMPS, HÜLS-Veba GmbH, Germany) glass fibers (Ahlstrom, Karhula, Finland) chopped to lengths of around 3 mm were used. The chopped fibers were incorporated into the acrylic resin powder at a concentration of 5 wt%.

Test specimens were prepared with a powder to monomer ratio of 10 g to 5 g, and the dough was packed in flasks under pressure of 1000 kPa. The polymerization procedure was carried out according to the manufacturer-instructions. After the polymerization, the flasks were cooled down to room temperature for 30 min, after which the test specimens were removed from the flasks. The resin specimens were finished to a size of 65 mm× 10 mm× 2.5 mm by using a 600-grit silicon carbide paper under water irrigation.

Fifty Paladent specimens were prepared in total. All the specimens were stored in distilled water at 37 ± 1 °C for 30 days. The specimens were divided into five groups according to the repair method with each group consisting of ten specimens.

Specimen preparation for repair

The groups of specimens studied are shown in Table 1. A group of intact specimens was used as control. The test specimens were sectioned in half. Central grooves (3 mm × 15 mm) were fabricated on each half of the test specimens and finished by rubbing with wet 240-grit silicon carbide paper. The samples were reassembled with a 3 mm butt-joint gap fixed in a metal mold to obtain the space for placing the repairing resin, which was used in all samples, except the control group (Figure 1).

Table 1: Studied groups.

Groups	Name	Repair Method	Manufacturer
Group 1	Control	Intact heat-polymerized acrylic resin	Paladent, Heraeus Kulzer GmbH, Wehrheim, Germany
Group 2	Acrylic	Autopolymerizing acrylic resin (without fiber)	Panacryl, Arma Dental Tıbbi Malzeme San. ve Tic. Ltd. Şti, Istanbul, Turkiye
Group 3	Stick	Stick glass fiber reinforced autopolymerizing acrylic resin	Ever Stick Crown and Bridge, Stick Tech Ltd, Turku, Finland
Group 4	Net (Woven)	Woven glass fiber reinforced autopolymerizing acrylic resin	StickNet, Stick Tech Ltd, Turku, Finland
Group 5	Chopped	Silanated chopped glass fibers reinforced autopolymerizing acrylic resin	γMPS, HÜLS-Veba GmbH, Germany, Ahlstrom, Karhula, Finland

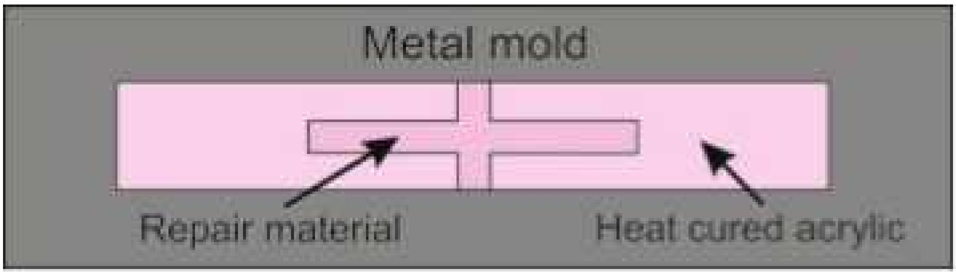

Figure 1. Specimen preparation before repairing procedure.

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Repair of specimens

For the repair procedure, the autopolymerizing resin in the absence of any reinforcing agents, and the autopolymerizing resin reinforced with unidirectional (Stick), woven (StickNet), and chopped glass fibers were used. Powder to monomer ratio of the autopolymerizing resin was 10 g to 5 g. For specimens repaired with the fiber reinforced autopolymerizing resin, additional monomer (0.7 ml per gram of fiber)[23] was used to impregnate the fibers. The repaired surfaces were treated with methyl methacrylate for 180 s. Stick and woven glass fibers were set between two autopolymerizing acrylic resin layers with a sandwich technique. The chopped glass fibers were randomly added into the polymer powder. This polymer-glass fiber blend was mixed with the monomer and the acrylic dough was placed into the prepared groove. Polymerization was allowed to take place at room temperature and atmospheric pressure for 60 min.

Testing procedure

After the repairing procedure, all specimens were carefully trimmed to their original dimensions by polishing with a 600-grit silicon carbide paper. The test specimens were stored in distilled water at 37 ± 1 °C for 48 h before testing. Three-point bending tests were carried out in a universal testing machine (Lloyd LF plus, Ametec Inc. Florida, USA) at a crosshead speed of 5 mm/min with a span of 50 mm. Specimens were set from the storage container directly onto the testing apparatus in wet condition. Fracture force and deflection values were displayed by the computer software associated with the testing machine.

The transverse strength and the elastic modulus values of all the specimens were obtained by inserting the values displayed by the computer in the formula shown below.

Fs: Transverse strength
Fe: Elastic modulus
Pm: Maximum force
l: Distance between the rests
b: Width of the test specimens
h: Height of the test specimens
d: Bending value

During the three-point bending tests, bending values could not be detected for samples in the stick group. Therefore elastic modulus values of this group were calculated using the slope of the linear portion of the stress-strain curve.

Statistical Analysis

After data collection, the mean, and the standard deviation (SD) values of transverse strength, and elastic modulus for each group were analyzed statistically with one-way ANOVA and by Tukey’s post-hoc test ($p \leq 0.05$) (SPSS, Statistical Package for Social Science, version 13.0).

RESULTS

Figure 2 shows the transverse strength obtained by the acrylic repairing methods. The average transverse strengths of the control and the stick fiber group were significantly higher than that of the autopolymerizing acrylic, net fiber, and chopped fiber group ($p<0.05$). The transverse strengths of the control and the stick fiber groups were comparable with $p>0.05$. Likewise, the transverse strengths of the autopolymerizing acrylic, net fiber, and chopped fiber groups were also similar to each other (with $p>0.05$). Also, the elastic modulus values of the stick fiber group were significantly higher than the other groups ($p<0.05$). There were no statistically significant differences when the other groups were compared among each other ($p>0.05$) (Figure 3).

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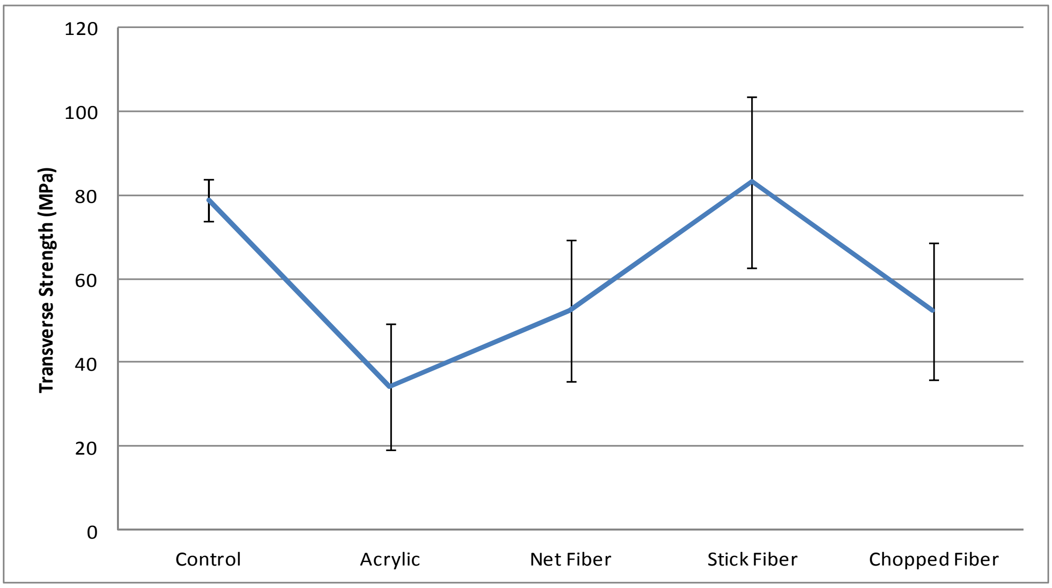

Figure 2. Transverse strength values of specimens obtained via various acrylic repair methods.

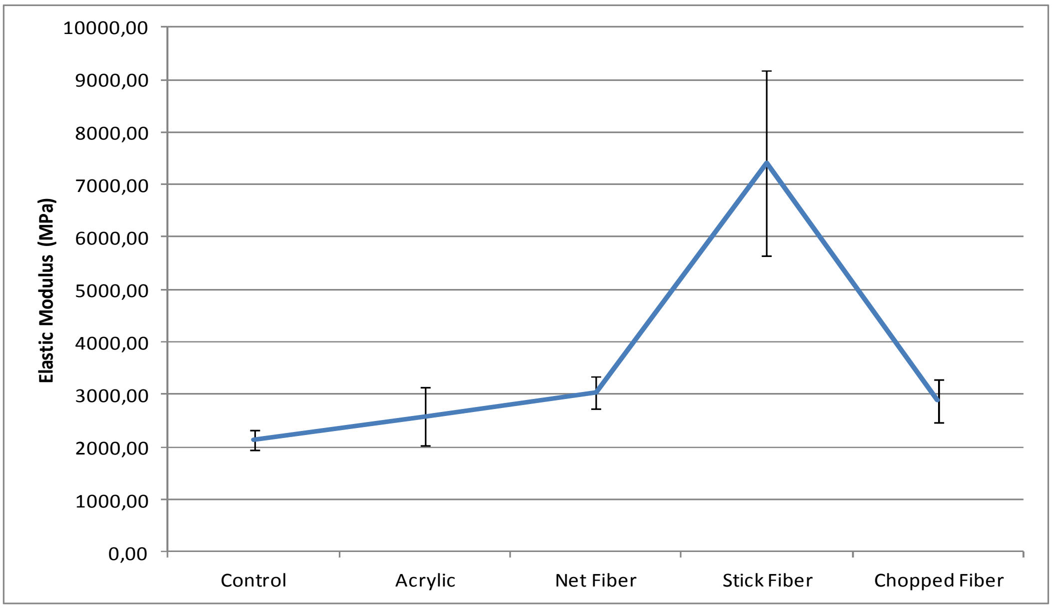

Figure 3. Elastic modulus values of specimens obtained via various acrylic repair methods.

While the specimens were fractured by the three-point bending test, the device could not detect any bending amount in stick fiber reinforced samples. Hence, the elastic modulus of this group of specimens could not be calculated with the formula. Elastic modulus values of this group were calculated using the slope of the linear portion of the stress-strain curve.

The specimens in the stick group were fractured after a longer time and with higher loads than the specimens belonging to other groups. The fragments of the specimens with the exception of those in the stick group were separated from each other.

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DISCUSSION

Fractures in acrylic dentures result from impact or bending forces. Impact forces are typically 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.[5]

Long prosthesis wearing period gives the subjects the opportunity to become trained and experienced complete-denture wearers with very few complaints. Older denture wearers seem to manage subjectively well with their dentures and hence, are often reluctant to obtain new ones. Despite the large number of functional faults and an objectively recognized need for replacement, only 10% of the dentures were found to be poor by the elderly themselves.[24] Therefore in most cases, instead of treating the elderly people by a new prosthesis, repairing and readjusting the old dentures is a better option.

In this context, the repairing procedure has to be rapid, easy to perform, inexpensive, and offer stability to the color and the dimensions of the denture.[25] Consequently, autopolymerizing acrylic resin has been the most preferred material for the denture repair.[26]

The ultimate goal of a denture repair is to restore or reinforce the denture's strength in order to avoid recurrent fractures.[25,27] Results from previous studies have shown that the strength of an autopolymerizing resin repair is only 18 to 81% of that of the intact heat-polymerized denture resin.[6,7,9,11,15,28] Consequently, recurrent fractures are a very common phenomenon. In this study, we also found with various methods that the strength values of the repaired specimens were 43–105% of the values shown by the intact heat-polymerized resin samples.

Different fiber types are used for fiber reinforced resins. Carbon fiber has a springy nature in handling and is less aesthetic than the other fibers. Some disadvantages of the aramid fibers are poor aesthetics and difficulties in polishing. In the case of polyethylene fibers, the surface treatment to improve the adhesion between fibers and denture base polymer is complicated and has not resulted in adequate adhesion.[4]

The use of glass fibers in the repairing procedure of removable dentures has been reported to be successful.[7,13] Vallittu[13] conducted a pilot clinical study (1–3 years) in which 22 complete and partial acrylic dentures were repaired with silanized glass fibers. This study concluded that incorporating the glass fibers for repairing the 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, any adjustment at the region of the glass fiber reinforcement was not required.[29] Nagai et al. [30] reported that repairing by reinforcing acrylic denture with methylene chloride pretreated glass fibers produced a higher elastic modulus and transverse strength than the control group.

Uzun and Keyf[31] reported that the repair made with PMMA can be strengthened by the addition of glass fibers in woven, longitudinal, and chopped forms. Glass fibers in woven form were the strongest PMMA reinforcers. The specimens repaired without fiber addition had weakened the PMMA. Also, unreinforced PMMA showed the least value of transverse strength.

Stipho[7] stated that the transverse strength of the specimens repaired with autopolymerizing acrylic resin reinforced with chopped glass fiber was higher than the specimens repaired without glass

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fibers. Stipho[7] also indicated that there were no significant mechanical advantages obtained by incorporating higher than 5% of glass fiber. Therefore, the amounts of chopped fibers used were set to 5% of the composite mass, in the presently reported study.

Kostoulas et al.[25] cut the specimens in the middle and fabricated a 3 mm butt-joint gap in the center of the specimens. Elhadiry et al.[32] introduced a cavity for the repairing procedure and stated that cavity fabrication had no significant effect on the flexural strength of the water-immersed repair. For placing the glass fiber-reinforcement, an additional 3.5 mm × 65 mm central channel perpendicular to the butt joint was created on these specimens. In our study, an additional central channel was fabricated in all the samples repaired to standardize the test methods.

Kostoulos et al.[25] stated that wetting the repair surface with methyl methacrylate for 180 s and repair with autopolymerizing resin did not significantly affect any of the mechanical properties of the heat-polymerized acrylic. However, Vallittu et al.[8] reported that appropriate wetting of the repair surface with methyl methacrylate dissolves the surface structure of PMMA and makes an important contribution to the strength of the repaired acrylic resin. Scanning electron micrographs revealed that after 60 and 180 s wetting periods, the PMMA dissolved with a smooth surface texture. Hence, in the present study, the specimens were wetted with methyl methacrylate for 180 s.

Keyf and Uzun[22] found that the transverse strength of the fiber-reinforced acrylic repair is significantly higher than that of the repair made with acrylic without fiber reinforcement. The results of our study also indicate that the fiber-reinforced repairs had a positive effect on the transverse strength.

Low values of deflection at fracture are associated with more rigid materials and reinforced specimens. Reinforcement with glass fiber or wire has been reported to lead to an improvement in strength but a decrease in deflection at fracture.[33,34] During the three-point bending tests, neither recordable nor visible bending values could be detected for samples in the stick group. The high elastic modulus values obtained from the stress-strain curve had verified this phenomenon. It was observed that these specimens fractured after longer duration of testing and with higher forces than the other groups. It is thought that this is because the stick fibers were manufactured to be used in the preparation of fiber reinforced composite fixed restorations and not for acrylics.

In the study by Nagai et al.,[30] specimens of all groups that were repaired with the use of reinforcement materials fractured at the end of the reinforcement apparatus. A higher value of transverse strength might have been obtained if a longer reinforcement apparatus had been embedded. For this reason, in the current study the reinforcement material size was set as 30 mm.

It has been indicated that the fracture after the repair mostly occurred between the denture base and the repair resin.[33] In our study, all the fractures occurred adhesively, between the repair and the base resin, in all test groups. The non-separated fragments of the stick group specimens are expected to decrease the risk caused by the hazardous effects of the acrylic base, such as swallowing or aspiration of the separated parts, and injury to the mucosa by the sharp ends of the fragments, in complete denture wearers.

CONCLUSIONS

According to this study, the transverse strength and elastic modulus of the stick group was higher than that of the other groups.

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