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Effect of glass-fiber usage on bond strength of acrylic resin to components of removable partial denture

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ABSTRACT

Aim: In order to improve the mechanical properties of polymethyl methacrylate (PMMA), more attention has been directed toward the glass fibers due to its good reinforcement capability. The purpose of this study was to determine the effect of glass fibers on the bond strength between reinforced acrylic resin and components of removable partial denture (RPD). **Materials and Methods:** Two types of denture teeth (conventional resin and cross-linked resin), two types of framework alloys (CoCr and Ti6Al4V) and heat-polymerized acrylic resin that was not reinforced and reinforced with glass fiber content of 1% and 5% were used. Reinforced and unreinforced acrylic resins were applied to both denture tooth and framework alloy samples to construct bonding area as 5 mm diameter. After polymerization of acrylic resin, samples were stored in distilled water for 2 days at 37°C; then they were thermocycled 5000 times (5–55°C). To record shear bond strength of samples, universal testing machine was used until failure occurred. The shear bond strength data were analyzed at 5% significance level. **Results:** The shear bond strength of CoCr alloy and cross-linked resin denture tooth samples didn't show any effect with reinforcement. But conventional resin denture teeth bonding enhanced with 5% fiber concentration; and Ti6Al4V, the addition of glass fiber, regardless of the ratio, affected the bonding strength in a positive way. **Conclusions:** Glass fiber reinforcement of the PMMA increased or did not aAQ4ffect, but never decreased the bonding strength between acrylic resin and component of RPD.

KEYWORDS: Acrylic resins, artificial teeth, dental alloy, glass fiber, shear strength

Introduction

Polymethyl methacrylate (PMMA) is the most widely used material for the construction of denture bases as it adequately satisfies esthetic demands and is superior to other materials in terms of easy manipulation and low cost.[1-4] However, it has some disadvantages, such as low fatigue and impact resistance. Intraorally repeated masticatory forces lead to fatigue phenomena, in addition, extraorally, high impact forces may occur as a result of dropping the dentures. Consequentially, fracture of the denture base can result.[5,6]

Therefore, much attention has been directed toward the reinforcement materials added to PMMA, such as metal fillers, carbon, aramid, ultra high molecular polyethylene (UHMPE), and glass fibers, to enhance their mechanical properties.[3,7-10] Silanized glass fibers are proven to have increased PMMA's fatigue and transverse strength; in addition, by fulfilling esthetic demands, they have become the best choice for the reinforcement of PMMA.[11] There have been many studies on the mechanical part of the reinforcement procedure, such as increasing transverse and fatigue strength of PMMA,[1,4,7,8] but none of them have explained the effect of glass fiber concentration in the bonding between reinforced PMMA and artificial teeth or metal alloy combinations in removable partial dentures (RPD).

In fact, stable and good contact is important in RPD by means of biological and mechanical aspects.[10,11] Otherwise, discoloration and deterioration of the denture base material can be observed. Meanwhile, microorganisms that may be infiltrated into the crevice can also cause an unfavorable soft tissue response.[8-11] Reinforcement of the base material is loosed the meaning in this kind of an unhealthy situation. Hence, if stable contact can be obtained among RPD

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components, this should prevent microleakage into the contact area and increase survival time of the denture in more healthy condition.

Accordingly, the aim of this study was to determinate the shear bond strength between unreinforced/reinforced PMMA with different fiber concentrations and different materials which are used as components of RPD (different material of artificial teeth and alloys).

Materials and Methods

Preparing metal alloy specimens

Thirty disc-shaped Co-Cr alloy (Wironit, Bego, Bremen, Germany) specimens (CoCr) which were conventionally cast in their wax molds (12 mm in diameter and 2 mm thickness) were filled with a silica-based investment in an induction casting machine, in accordance with the manufacturer's instructions.

Titanium alloy (Ti6Al4V alloy, TIMET Industry, Izmit, Turkey) was obtained from the manufactures as a cylinder, measuring 12 mm in diameter and 50 cm in length. 30 titanium alloy specimens (Ti6Al4V) were sliced as 2 mm thickness by a CNC machine (Triger S: 1050, Simge Machine, Kayseri, Turkey) which had a special cooling apparatus.

All alloy specimens were then embedded in autopolymerizing PMMA (Meliodent, Heraeus Kulzer Ltd., Newbury, UK) with dimensions of 15 mm × 15 mm × 6 mm. Finally, the surfaces of specimens were sandblasted with 110 μm Al3O2 powder with 0.5 MPa pressure from a 5 mm distance for 10 s [Figure 1a].

Preparing artificial tooth specimens

Conventional resin denture teeth (Gnathostar, Ivoclar/Vivadent, Schaan, Liechtenstein) and cross-linked resin denture teeth (SR-Orthosit-PE, Ivoclar/Vivadent, Schaan, Liechtenstein) were used in this study as the artificial teeth. Sixty-first maxillary molar teeth were chosen for both of two artificial teeth. Their ridge lap surfaces were grounded to 2 mm by burs. Then they were embedded from their occlusal surfaces in autopolymerizing PMMA with dimensions of 15 mm × 15 mm × 6 mm, like previous studies (marra). The ridge lap surface of each specimen was ground flat with 600 grit wet/dry sandpaper. The specimens were then cleaned with water [Figure 1b].

Preparing the bonding area

One hundred and twenty wax patterns, which had a diameter of 5 mm and thickness of 2 mm, were prepared and stuck to the surfaces of both the artificial teeth and the metal alloys by finger pressure to construct the bonding surface area for the PMMA. The specimens were placed in flasks, and the lost wax technique was used according to manufacturer's instructions. After losing wax and before applying PMMA,

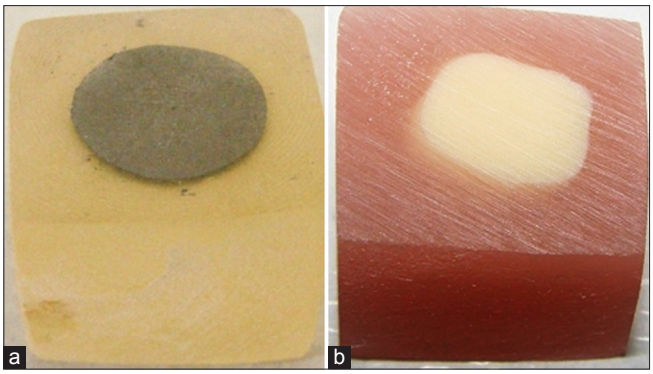

Figure 1: A sample with framework alloy (a) and denture tooth (b), before acrylic resin polymerization

one layer of metal primer (Alloy Primer, Kuraray Co., Japan) was applied to the metal alloy specimens with a brush and left for 5 min. Then, heat-polymerized PMMA (Meliodent, Heraeus Kulzer Ltd., Newbury, UK) was applied to the specimens following the manufacturer's instructions. Ten specimens for each material of RPD component were prepared by this method.

Reinforcement and polymerizing of polymethylmethacrylate

In order to reinforce the PMMA, chopped in 2 mm length silanized E-glass fibers (A174-KRC2M Cam-Elyaf A.Ş., Kocaeli, Turkey) were used for both 1% and 5% content. Extra monomer (0.7 ml/1 g of glass fibers) was used so as not to decrease the wetting of the PMMA powder. In this procedure, glass fibers were added to PMMA powder, and extra monomer was added to the PMMA liquid. Heat-polymerized PMMA was mixed according to the manufacturer's instructions, and the dough resin was packed directly into the molds of the bonding area and heat-polymerized. The flasks were opened, and any excess PMMA was cleaned with burs.

Thermocycling and shear bond strength test

All specimens were stored at 37°C for 48 h in distilled water and then they were thermocycled between 5°C and 55°C with 30 s dwell times for 5000 cycles (Nova Ticaret, Konya, Turkey). Each specimen was adjusted for testing, and a shear bond strength test was performed on a universal testing machine using a crosshead speed of 1 mm/min (Elista, Istanbul, Turkey). Fracture loading was recorded in Newton and converted to MPa values by dividing Newton values by the bonding area ($N/\pi r^2$). Debonded surfaces were examined with a camera (Sony Cybershot H5, Japan) to evaluate failure modes.

Statistical analyses

Statistical analyses were performed with SigmaStat (Aspire Software International, Washington, USA) at 95% confidence interval. The data were evaluated first with the Kolmogorov–Smirnov normality test ($\alpha = 0.05$). The

normal distributed bonding strength data were then tested with two-way ANOVA and post-hoc Holm-Sidak test.

Results

Two-way ANOVA revealed that different reinforcements of PMMA with fiber and different materials significant effect on shear bond strength amongst themselves ($P < 0.05$) [Table 1]. The results of the shear bond strength test and *post-hoc* comparisons are given in Table 2. And failure modes of specimens summarized on Figure 2.

When conventional resin denture teeth were the artificial teeth, 5% reinforced PMMA was showed higher bonding strength than unreinforced PMMA ($P < 0.05$). The reinforcement factor did not show statistical difference at bonding strength in the cross-linked resin denture teeth and CoCr ($P > 0.05$). In the Ti6Al4V, quantity of reinforcement of PMMA did not have an effect ($P > 0.05$), but the reinforcement of PMMA enhanced bonding strength between them ($P < 0.05$).

The bonding strength comparisons of material factors within the unreinforced and 5% reinforced PMMA, conventional resin denture teeth were bonded higher than CoCr and Ti6Al4V ($P < 0.05$). However, no significance difference was found for material factors in 1% reinforcement of PMMA ($P > 0.05$).

Discussion

This study aimed to explain how the concentration of silanized glass fiber adding to PMMA for mechanical reinforcement is affected bonding between PMMA and different components of RPD. In order to reinforce silanized glass fibers was used, may be the best choice from other fibers, such as aramid, carbon, and UHMPE, because of well-documented evidence of their improved flexural properties, fatigue resistance, impact strength,[3,7,8,12] and good adhesion of glass fibers to denture base resin.[9,13]

Most studies investigated mechanical properties to find optimum proportion of fiber reinforcement. Stipho[8] found that adding shortly chopped glass fibers to PMMA powder

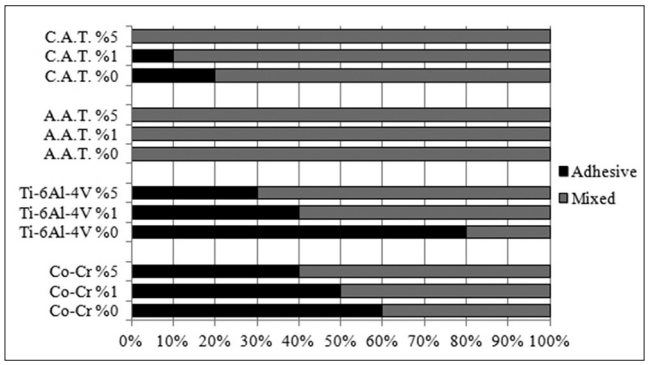

Figure 2: Percentage of failure mode of groups

was an effective and easy way to strengthen PMMA, and also stated that adding 1% content of glass fiber to PMMA improved the mechanical properties best. Ladizesky *et al*.[14] reported that the same glass fiber concentration of 1% increased the transverse strength up to 48%. Researchers did not recommend >5% glass fiber content in PMMA and claimed that more than a 15% concentration of glass fibers would decrease the strength instead of increasing it.[15,16] Gutteridge also stated that the glass fiber concentration of 1% was the best for the reinforcement of PMMA and claimed that concentrations >1% glass fibers would affect the chemical structure of the PMMA.[16] Taking these studies into consideration, the optimum ratio of 1% and the limit ratio of 5% glass fiber concentration were used in this study to reinforce PMMA.

According to the results of the present study, glass fiber addition to PMMA did not decrease the bonding strength, even increased it for some materials. This situation may be explained by the dual functional silanized fiber and metal primers.[17,18] With the help of silane application, glass fibers were successfully impregnated in the PMMA and acted as filling materials in the resin matrix. One of the dual layers of silane was attached to the fibers and the other one to the PMMA matrix. At this point, how the addition of glass fiber works, may be important. At the glass fiber addition stage, glass fibers were well-impregnated in the PMMA matrix with extra monomer. In this way, the glass fibers do not act like a foreign material in the bonding area and promote bonding between PMMA and the components of RPD.

According to results of this study, both conventional resin denture teeth and cross-linked resin denture teeth bonding to reinforced or nonreinforced PMMA had similar bonding strength; and for unreinforced PMMA bonding to artificial teeth findings are same with the previous studies.[19] But, though cross-linked resin denture teeth did not show any differ by means of bonding with reinforcement, conventional resin denture teeth bonding enhanced with 5% fiber concentration. The authors of this study think that PMMA and conventional resin denture teeth are came from same origin of material as an acrylic resin; and fiber being at the bonding zone increases strength of bonding of this kind of complex. Even if 1% reinforcement showed increase in bonding, this was not observed statistically. But the enhancement at the bonding was observed with the increasing reinforcement. On the other hand, cross-linked resin denture teeth bonding did

Table 1: Results of two-way ANOVA

Factors	Sum of squares	*df*	Mean squares	F	*P*
Reinforcement	1144.664	2	572.332	7.799	<.001
Materials	790.408	3	263.469	3.590	0.016
Reinforcement* materials	984.674	6	164.112	2.236	0.054
Error	7852.653	107	73.389		
Total	10793.513	118			

Table 2: Shear bond strengths and *post-hoc* evaluation of groups

Material	Fiber Reinforcement		
	None (0%)	1% Concentration	5% Concentration
Conventional resin denture teeth	39.257±6.39[a]	41.265±5.44[a,b]	48.959±7.48[b]
Crosslinked resin denture teeth	4.773±8.41[a,c]	40.553±8.74[a]	39.425±12.88[a,b,c]
Cobalt-Chrome alloy (CoCr)	37.632±8.19[b,c]	41.815±6.23[a,c]	36.748±5.35[c,a]
Grade 5 titanium alloy (Ti6Al4V)	7.067±12.43[b]	42.604±4.20[a]	38.463±11.34[a]

Different superscript letters shows statistical difference vertically and horizontally ($P<.05$)

not show any difference with fiber concentration. Authors of this study think the reason that cross-linked resin denture teeth is a different material (isosit) from PMMA; and it is demonstrated that the teeth's ridge-lap surface composition can affect the polymer tooth bonding to the denture base polymer.[20-22]

Many researchers compared the bond strengths between PMMA and metal alloys to which metal primers were applied, or not applied, and metal primers increased bonding strength.[17,18,23-25] Therefore, authors of this study determined metal primer application as a standard for metal surface treatment.

According to the findings of alloy groups, glass fiber reinforcement of PMMA, did not affect bonding strength at CoCr. However, in the Ti6Al4V, the addition of glass fiber, regardless of the ratio, affected the bonding strength between PMMA and the alloy in a positive way. This enhancement of bonding strength can be seen failure modes [Figure 2]. Mixed failure of reinforced PMMA-Ti6Al4V specimens shows more mixed failure than unreinforced PMMA-Ti6Al4V. Actually, this finding comes from low bonding strength between Ti6Al4V and nonreinforced PMMA. But this lowest bonding strength of this study did not differ from previous studies.[23-27]

On the other hand, especially in the titanium made attachments of implant-supported dentures, there is very little space in the PMMA denture base. Patients, who use these dentures, apply more chewing force as they feel free to eat whatever they want as a result of having more retentive and comfortable dentures. Because of these two factors, denture base resins can fracture.[22,28] According to result of this study, probable problems in Ti6Al4V and PMMA can be solved by fiber reinforcement of PMMA and implant-supported dentures, become safer by means of bonding between partial denture and components of PMMA. Further *in vivo*/*in vitro* long-term studies should be conducted this issue.

Within the limitations of the present study, the glass fiber content in PMMA did not affect the bonding between artificial teeth-PMMA and metal alloy-PMMA combinations in a negative way. On the contrary, the reinforcement of PMMA with glass fiber increased the bonding strength between Ti6Al4V-PMMA and conventional resin denture teeth-PMMA combinations.

Clinical significance

Reinforcement of PMMA increased the bonding strength when conventional resin denture teeth and titanium grade 5 alloy were used.

Acknowledgments

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