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ARTICLE

EFFECT OF DIFFERENT MECHANICAL SURFACE TREATMENTS ON FLEXURAL STRENGTH OF REPAIRED DENTURE BASE.

Efecto de diferentes tratamientos superficiales mecánicos sobre la resistencia a la flexión de la base de la dentadura reparada.

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ABSTRACT:

Aim: To assess the effect of different mechanical surface treatments on flexural strength of repaired denture base.

Material and Methods: Sixty bar-shaped specimens of heat-polymerized acrylic resin were fabricated, and divided into six groups (n=10). All specimens, except the positive control group (group PC), were sectioned into halves to create a 1-mm clearance. A negative control group with no surface treatment (group NC) was also considered. Other groups underwent different surface treatments: group Laser; treated with erbium: yttrium-aluminum-garnet (Er:YAG) laser, group APA; airborne-particle abrasion (APA), group APA plus Laser; a combination of laser and APA, and group Bur; bur grinding. After measuring surface roughness (Ra) with a profilometer, all sectioned specimens were repaired by auto-polymerizing acrylic resin, and thermocycled afterward. Three-point bending test was performed by a universal testing machine. Data were statistically analyzed ($\alpha=0.05$).

Results: The mean surface roughness of all experimental groups were significantly higher than that of group NC ($p<0.05$). The mean flexural strength of all groups was significantly lower than that of group PC ($p<0.05$). Group B had significantly higher flexural strength than the other surface-treated groups ($p<0.05$). Group Laser had significantly higher flexural strength than groups APA ($p=0.043$) and APA plus Laser ($p=0.023$). No significant difference was found between groups APA and APA plus Laser ($p=0.684$).

Conclusion: All surface treatments increased the surface roughness and flexural strength compared with the untreated group. The highest flexural strength was observed in specimens treated by bur grinding and then laser, however, it was still significantly lower than intact specimens.

KEYWORDS:

Polymethyl methacrylate; Denture repairs; Dental air abrasions; Erbium doped yttrium aluminum garnet lasers; Complete denture; Acrylic resins.

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RESUMEN:

Objetivo: Evaluar el efecto de diferentes tratamientos superficiales mecánicos sobre la resistencia a la flexión de la base de la prótesis reparada.

Material y Métodos: Se fabricaron sesenta especímenes en forma de barra de resina acrílica termo-polimerizada y se dividieron en seis grupos (n=10). Todas las muestras, excepto el grupo de control positivo (grupo PC), se seccionaron en mitades para crear un espacio libre de 1 mm. También se consideró un grupo de control negativo sin tratamiento superficial (grupo NC). Otros grupos se sometieron a diferentes tratamientos superficiales: grupo Láser; tratados con láser de erbio: itrio-aluminio-granate (Er:YAG), grupo APA; abrasión por partículas en el aire (APA), grupo APA más láser; una combinación de láser y APA, y grupo Bur; molienda de fresas. Después de medir la rugosidad de la superficie (Ra) con un perfilómetro, todas las muestras seccionadas se repararon con resina acrílica de autopolimerización y se sometieron a termociclado. La prueba de flexión de tres puntos se realizó con una máquina de prueba universal. Los datos se analizaron estadísticamente (α=0,05).

Resultados: La rugosidad superficial media de todos los grupos experimentales fue significativamente mayor que la del grupo NC (p<0,05). La resistencia media a la flexión de todos los grupos fue significativamente menor que la del grupo PC (p<0,05). El grupo B tenía una resistencia a la flexión significativamente mayor que los otros grupos tratados en la superficie (p<0,05). El grupo Láser tuvo una resistencia a la flexión significativamente mayor que los grupos APA (p=0,043) y APA más Láser (p=0,023). No se encontró diferencia significativa entre los grupos APA y APA más Láser (p=0,684).

Conclusión: Todos los tratamientos superficiales aumentan la rugosidad de la superficie y la resistencia a la flexión en comparación con el grupo sin tratar. La resistencia a la flexión más alta se observó en las muestras tratadas con fresado y luego con láser; sin embargo, aún era significativamente más baja que las muestras intactas.

PALABRAS CLAVE:

Polimetil Metacrilato; Reparación de la Dentadura; Abrasión Dental por Aire; Láseres de Estado Sólido; Dentadura Completa; Resinas Acrílicas.

INTRODUCTION.

Complete dentures are the most common treatment for edentulism.[1-3] Considering financial reasons, conventional complete dentures are still a treatment of choice.[2] Polymethyl methacrylate (PMMA) is commonly used for fabrication of denture bases due to its low cost, ease of use, satisfying appearance, and dimensional stability.[4-6] However, inappropriate design or manufacturing process, excessive force application, ridge resorption, or tooth wear can result in inadequate mechanical strength in long-term, inherent stress accumulation, and eventually fracture.[7]

Fabrication of a new denture requires several appoint-ments and the patient has to spend some time without denture; therefore repair may be preferred over replacement.(7-9) The repair procedure should be inexpensive, easy, and provide adequate strength, dimensional stability, and color match with the original denture.[8,10] The method of choice is to use auto-polymerizing acrylic resin.[8,11] It is easily available, does not require laboratory processing, and can be performed chairside; thus, the patient spends less time without denture.[10] However, repairing of fractured denture base is not free of limitation, and refracture of repaired dentures often occurs at the site of repair.[8,12,13]

Aside from the time and cost, the patient often loses his trust in the dentist. Therefore, researchers are looking for solutions to overcome this problem. Bur grinding,[8] airborne-particle abrasion (APA),[8, 14] and lasers[14,15] are among mechanical surface treatments by which the contact area between the denture and repair material would increase.

Laser is a relatively safe and easy modality for surface treatment of materials.[15] Several studies have investigated laser application for surface treatment of denture bases for different purposes such as increasing the bond strength of soft-liners to denture base, or improving the bond strength between the denture base and acrylic teeth.[4,5,16-18]

However, to the best of authors' knowledge, there is only one study which has assessed the effect of irradiation with erbium: yttrium-aluminum-garnet (Er:YAG) laser on the repair bond strength of fractured conventional denture base.[14] Despite that surface roughness seems promising to increase bonding area and mechanical retention,[12] it has not been evaluated quantitatively in studies in which different surface treatments were applied for repairing fractured conventional dentures. In fact, the effect of enhanced surface roughness after surface treatments on the resultant repair bond strength of fractured conventional dentures has not been investigated yet. Thus, this study aimed to evaluate the effect of different mechanical surface treatments on flexural strength of repaired conventional denture base. The null hypotheses in this study were two-fold:

(i) different surface treatments have no effect on the flexural strength of repaired denture base, and

(ii) different surface treatments have no effect on the surface roughness of treated denture bases.

MATERIALS AND METHODS.

In this experimental study, 60 bar-shaped specimens of heat-cured PMMA measuring 80 mm in length, 10 mm in width, and 4 mm in thickness were fabricated. To prepare the test samples, bar-shaped metal patterns were fabricated, coated with a separating medium, and invested into a 50:50 mixture of plaster gypsum and stone in a lower portion of a metallic flask. A mechanical vibrator was used to prevent entrapment of air.[19] After setting, the stone and the patterns were coated with a layer of separating medium. The upper portion of the flask, filling with the same mixture, was placed over the lower portion. After covering the flask with stone, it was left to set. Afterward, the flask halves were separated, and the metal patterns were removed. Then, the stone mold was cleaned and coated with a separating medium twice. The heat-polymerized denture base resin (Triplex Hot-V, Ivoclar Vivadent, Schaan, Liechtenstein) was mixed according to manufacturer's instructions with a powder: liquid ratio of 23.4 gr to 10 ml. The resin was left to reach the dough stage before packing. After positioning the upper portion of the flask over the lower portion, the flask was placed under a hydraulic press unit (under 3000 Psi hydraulic press, Mehrdent, Karaj, Iran) to apply a slow pressure which allows the acrylic dough to flow evenly.

After opening the flask and removing the excess material, specimens were polymerized in a processing unit (Mestra R-080402, Mestra, Txorierri, Spain) according to the standard protocols for fabrication of conventional dentures. Before deflasking, specimens were kept at room temperature for 1 hour to cool down.(2, 19) For elimination of residual monomer, specimens were immersed in 37±1°C water for 50 ±2 hours. An acrylic bur was used to remove flashes and accesses of specimens. Then, all specimens were finished with 80, 320, 400, and 1000-grit silicone paper under water coolant, respectively, following by polishing with pumice.[19] Specimens were measured with a digital caliper (Mitutoyo ABSOLUTE 500-197-20, Mitutoyo Corp., Kawasaki, Japan) with the accuracy of 0.02 mm to verify the length, width and thickness. Finally, specimens were divided into six groups (n=10): intact specimens as the positive control (PC), repaired specimens with no surface treatment as the negative control (NC), surface treatment with Er:YAG laser (Laser), airborne-particle abrasion (APA), a combination of laser and APA (APA plus Laser), and bur grinding (Bur).

All specimens, except the group PC, were sectioned into halves using a diamond disc (Sinter Flex, Drendel and Zweiling Diamant, Berlin, Germany) to provide a 1-mm clearance. The joint surface contour of each half was beveled at 45 degrees such that when they were aligned together, the upper edges were about 6 mm apart (Figure 1). To standardize repair gap width and joint surface contour, a guideline was drawn on the top and the button surfaces of each specimen. In addition, a costume-made device with the same internal dimensions and bevel was used. All procedures were performed by the same operator.

In group Laser, the bonding surface of the specimens was treated with Er:YAG laser (Smart 2940D Plus, DEKA, Florence, Italy) (2940 nm, 1.5 W, 150 mJ, 119.42 J/cm^2). Laser was irradiated at a 10-mm distance using a handpiece with a 4-mm diameter tip (spot size: 4 mm) in pulse mode (10 Hz) with 700 µs pulse duration for 20 seconds. Irradiation of laser was performed under 5 mL/min water spray cooling in a sweeping motion.[20, 21]

In group APA, 250-µm airborne particles were applied to the beveled specimens in a sandblaster under 0.2 MPa pressure at a 10-mm distance for 10 seconds.[14] In group APA plus laser, laser treatment and airborne-particle abrasion of the specimens were performed as described for the groups Laser and APA, respectively. In group Bur, the beveled specimens were roughened by moving a low-speed round tungsten carbide bur (Dia.Tessin, Vanetti SA, Gordevio, Switzerland) in one direction for 10 seconds. All procedures were performed by the same operator. Afterward, the specimens were cleaned for 10 seconds in an ultrasonic bath containing deionized water, and air-dried.

Before repairing fractured specimens, the surface roughness (Ra value) of each half of sectioned specimens was measured three times by using a profilometer (TR200, Time Group Inc., Beijing City, China) with a 0.25-mm cut off at 0.1 mm/second speed and a resolution of 0.001 µm. The mean of the six surface roughness values for each specimen was calculated and reported.

The two pieces of each specimen were placed in a template obtained from an intact specimen. The gaps were filled with auto-polymerizing acrylic resin (ProBase Cold; Ivoclar Vivadent, Schaan, Liechtenstein). Afterward, they were placed in 40°C water in a 2-bar pressurized pot (Mestra R-030425, Mestra, Txorierri, Spain) for 15 minutes. Specimens were repaired slightly over due to consideration of shrinkage after polymerization.

Then, specimens were polished. The length, width and diameter of each specimen were measured again using a digital caliper to avoid possible changes in the specimen dimensions that may occur during polishing. After the repairing procedure, the specimens were incubated for 24 hours in an aqueous medium at 37 ±1°C, and then thermocycled between 5-55°C with a 20 seconds dwell time for 5000 cycles.

Finally, to calculate the flexural strength values in Megapascals (MP), a universal testing machine (STM20, Santam, Tehran, Iran) was used to record load at fracture in Newtons (N). Load was applied to the center of the repair area at a crosshead speed of 5 mm/min until fracture. Next, the following formula was used:

$$S = \frac{3wl}{2bd^2}$$

Where S is the flexural strength or fracture strength in N/mm^2, w is the load applied for fracture in Newtons (N), l is the distance between the two vertical rods (50 mm), b is the width of specimen (10 mm), and d is the thickness of specimen (4 mm).

Fractured specimens were observed under a video measuring machine (C-Class Vision Measurement Machine; Easson Optoelectronics Technology Co., Suzhou, China) to categorize the failure type (adhesive or cohesive) (Figure 2). Specimens with a complete layer of an auto-polymerized acrylic resin on both repaired surfaces were classified in the cohesive failure group.

Data were analyzed with SPSS software version 26 (IBM Corp., Armonk, NY, USA). Normal distribution of the data and the homogeneity of variances were analyzed with the Kolmogorov-Smirnov and the Levene test, respectively. The results showed normal distribution of surface roughness data in all groups, and the assumption of homogeneity of variances was also met. Therefore, ANOVA followed by the Tukey test was used to compare the mean surface roughness of the study groups. In addition, analysis of the flexural strength values revealed that the data were not normally distributed. Therefore; the Kruskal-Wallis test was used to compare the mean flexural strength of the study groups. Pairwise comparisons were carried out using the Mann Whitney test with Bonferroni adjustment. Level of significance was considered at 0.05.

RESULTS.

The mean and standard deviation values of surface roughness and flexural strength of the study groups are shown in Table 1.

Among the study groups, group Bur showed the highest mean surface roughness (0.95 ±0.20µm), while the lowest value was noted in group NC (0.53 ±0.11µm). Based on the results of the ANOVA test, there was a significant difference among the study groups in terms of surface roughness (*p*<0.001). The mean surface roughness of all surface-treated groups were significantly higher than that of NC (*p*<0.05). Group Bur had significantly higher surface roughness than group APA (v=0.047).

No significant difference was found among the other surface-treated groups regarding the surface roughness (*p*>0.05, Table 2). Among the surface-treated groups, Group Bur showed the highest mean flexural strength (34.20 ±2.19 MPa), while the lowest value was noted in group APA plus Laser (28.90 ±1.81 MPa). Based on the results of Kruskal-Wallis, there was a significant difference among the study groups in terms of flexural strength (*p*<0.001). Group Bur had significantly higher flexural strength than groups Laser (*p*=0.003), APA

Figure 1. Diagram of the preparation of specimens for repairing procedure.

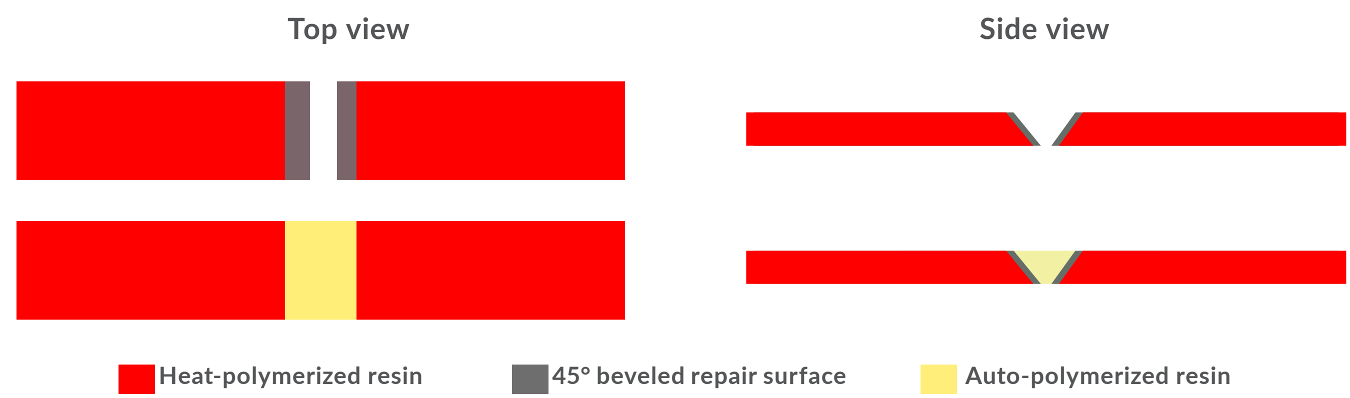
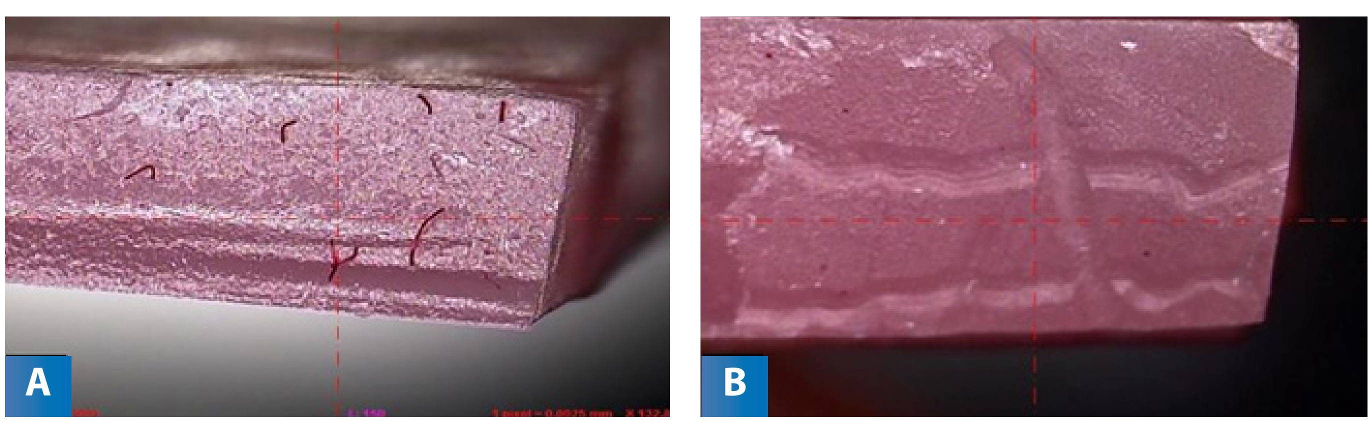


Figure 2. Modes of failure.



A: Cohesive. **B:** Adhesive

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Table 1. Mean and standard deviation values for the pull-out tests per group.

Group	Surface roughness		Flexural strength		
	Mean	SD	Mean	SD	Median
PC	-	-	67.37	4.43	67.31
NC	0.53	0.11	25.03	2.17	25.42
Bur	0.95	0.20	34.20	2.19	34.24
Laser	0.76	0.22	31.06	1.57	31.16
APA	0.74	0.11	29.26	1.62	29.41
APA plus Laser	0.78	0.13	28.90	1.81	28.82

APA: Treated with airborne-particle abrasion. **APA plus Laser:** Treated with a combination of laser and airborne-particle abrasion. **Bur.** Treated with bur grinding. **Laser treated with Er:** YAG laser. **NC:** Negative Control. **PC:** Positive Control. **SD:** Standard Deviation.

Table 2. Pairwise comparisons of study groups regarding surface roughness with Tukey test.

Group	NC	Bur	Laser	APA	APA plus Laser
NC	---				
Bur	<.001*	---			
Laser	0.024*	0.089	---		
APA	0.049*	0.047*	0.999	---	
APA plus Laser	0.009*	0.193	0.995	0.965	---

APA: Treated with airborne-particle abrasion. **APA plus Laser:** Treated with a combination of laser and airborne-particle abrasion. **Bur.** Treated with bur grinding. **Laser treated with Er:** YAG laser. **NC:** Negative Control. **PC:** Positive Control. **SD:** Standard Deviation.

Table 3. Pairwise comparisons of flexural strength of study groups with Mann-Whitney test and Bonferroni adjustment.

Group	PC	NC	Bur	Laser	APA	APA plus Laser
PC	---					
NC	<0.001*	---				
Bur	<0.001*	<0.001*	---			
Laser	<0.001*	<0.001*	0.003*	---		
APA	<0.001*	<0.001*	<0.001*	0.043*	---	
APA plus Laser	<0.001*	0.001*	<0.001*	0.023*	0.684	---

APA: Treated with airborne-particle abrasion. **APA plus Laser:** Treated with a combination of laser and airborne-particle abrasion. **Bur.** Treated with bur grinding. **Laser treated with Er:** YAG laser. **NC:** Negative Control. **PC:** Positive Control. **SD:** Standard Deviation.

(p<0.001), and APA plus Laser (*p*<0.001).

Group Laser had significantly higher flexural strength than groups APA (*p*=0.043) and APA plus Laser (*p*=0.023). The mean flexural strength of all groups was significantly lower than that of group PC and higher than that of group NC. No significant difference was found between groups APA and APA plus Laser (*p*=0.684, Table 3).

About 70%, 50%, 60%, 70%, and 30% of the observed fractures in groups Laser, APA, APA plus laser, Bur, and NC were cohesive, respectively.

DISCUSSION.

There was a significant difference among study groups in terms of surface roughness and flexural strength. Thus, the null hypotheses regarding no significant effect of surface treatment on the flexural strength of repaired denture base and surface roughness of treated denture were rejected.

In previous studies a 1.5-3 mm gap has been considered between the repaired surfaces.[8,11,14] Since repairing the gaps wider than 1 mm may weaken the denture base repair strength, a 1 mm gap was considered in this study.[22] Also, the contour of joint surface is of utmost importance in the success of repaired denture.[9] The geometry of 45 degree bevel increases the interfacial bonding area, changes the pattern of interfacial stress from more destructive forces towards the shear forces, and increases the risk of cohesive failure as such.[8] Thus, a 45 degree bevel was performed in this study.

Evidence shows that thermocycling is a suitable technique for simulation of thermal alterations in the oral environment, and can predict the long-term clinical service of restorations. In this study, 5000 thermal cycles, corresponding to 4-5 years of clinical service were applied.[23] It should be noted that thermocycling can result in a reduction of strength of denture base resins due to thermal stress, and absorption of water.[2] In fact, the heat stress can increase the distance between polymer chains, which may lead to further water absorption. (24) It should be noted that resins which contain less amount of cross-linking agents are more susceptible to absorb water during thermocycling. (24) Probase Cold, used for repairing sectioned specimens in this study, contains only less than 5% butandiol as cross-linking agent, which may make it more susceptible to water uptake.[25]

It is theoretically accepted that mechanical surface treatments can cause irregularities in PMMA and subsequently increase the bond strength.[21] According to the current results, all mechanical preparation methods significantly increased surface roughness and flexural strength. Among all surface treatments, bur grinding yielded the highest flexural strength. Therefore, bur grinding can be the surface treatment of choice when repairing fractured denture base, and is thus considered as a temporary solution for patients who cannot spend some time without denture. Controversy exists among studies regarding positive effect of bur grinding.[4,12,18,21,26] However, there is a limited information regarding bur grinding of PMMA to enhance the strength of repaired denture base.[12,21,26] Similarly, in our previous study, we observed that bur grinding of fractured three-dimensional-printed (3D-printed) denture base yielded a significant stronger flexural strength compared to untreated sectioned group.[21] Contrary to this study, Yadav *et al.*,[26] reported the inefficiency of bur grinding to improve the flexural strength of fractured denture base. They believe that chemical surface treatment is preferred over mechanical surface treatment for this purpose.[26] Moreover, Li *et al.*,[12] reported that grinding is not necessary for repairing non-aged fractured 3D-printed dentures, but beneficial for repairing aged fractured ones. This difference can be associated with different fabrication methods and use of silicon carbide abrasive paper for simulation of bur grinding.

It is suggested that the increased surface area and altered surface texture after irradiation of laser may cease penetration of auto-polymerizing acrylic resin into the created porosities.[4] In fact, auto-polymerizing acrylic resin can penetrate into

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the porosities created by laser. In this experimental study, surface treatment with laser yielded significantly superior flexural strength for denture base repair, compared with the untreated group. This finding was in line with our previous study.[21] The positive effect of irradiation of Er:YAG laser was also reported by Akin *et al*.,[18] to enhance the bond strength of denture base and acrylic teeth, and Alkurt *et al*.,[14] to yield a higher repair strength of fracture denture base.

However, Aziz *et al*.,[15] showed that surface treatment with diode laser had no significant effect on flexural strength. This difference can be attributed to the use of a different type of laser, which can cause different morphological alterations in the surface. Moreover, they evaluated the flexural strength of the denture base after reline, not repair.

This study indicated that APA, and a combination of APA and irradiation with laser yielded a statistically increased surface roughness and flexural strength. However, some studies have pointed to the insufficient size of irregularities created by airborne-particles, and the stress which may occur at the interface.[16,27] In line with this study, Nakhaei *et al*.,[27] reported the positive effect of these surface treatments on altering the surface of acrylic denture base.

Assessment of the mode of failure of specimens revealed that the groups Bur and Laser mostly showed cohesive fracture. Similarly, Li *et al*.,[12] reported dominant cohesive failure mode in the bur grinding group. However, the results of this study was in contrast with the results of studies regarding the use of laser.[4,14,18] This difference may be contributed to different type of laser,[4] different duration of irradiation,[14] or different output power of laser.[18] Thus, considering the positive results regarding the use of Er:YAG laser for preparation of denture base for repair, further studies are warranted to more precisely scrutinize the mechanism of effect of laser and its parameters.

In this study auto-polymerizing resin was used to repair the fractured denture base. Although auto-polymerizing resin allow for a chairside repair, it should be mentioned that auto-polymerizing resin may show more toxicity and lower strength compared to heat-polymerized resin.[2,28]

The *in vitro* design of this study may not perfectly simulate the clinical setting. Bar-shaped specimens cannot be a true representative of an actual denture either. In addition, denture base fracture may occur as the result of fatigue failure. Thus, cyclic loading is recommended for future studies. Also, further *in vitro* studies and clinical trials are required, particularly on digitally-fabricated dentures, and different parameters of Er:YAG laser.

CONCLUSION.

Within the limitations of this study, it may be concluded that all mechanical surface treatment methods evaluated in this study yielded a higher surface roughness and flexural strength than the untreated group. However, the obtained strength was still signifi-cantly lower than the primary denture strength. Groups Bur and then Laser, yielded the highest repair bond strength, and showed cohesive fracture in most specimens.

Conflict of interests:

The authors declare that they have no competing interests.

Ethics approval:

Not applicable. This is *in vitro* study.

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Authors' contributions:

Asli NH and Falahchai M: Contributed to conception and design; contributed to acquisition and interpretation; contributed to acquisition, analysis, and interpretation; critically revised manuscript; gave final approval; agrees to be accountable for all aspects of work ensuring integrity and accuracy.
Rahimabadi S, Asli MN and Belyani N: Contributed to conception and design; contributed to acquisition and interpretation; critically revised manuscript; gave final approval; agrees to be accountable for all aspects of work ensuring integrity and accuracy.
Asli NH and Falahchai M: Contributed to conception and design; contributed to acquisition and interpretation; contributed to acquisition, analysis, and interpretation; critically revised manuscript; gave final approval; agrees to be accountable for all aspects of work ensuring integrity and accuracy.
Rahimabadi S, Asli MN and Belyani N: Contributed to conception and design; contributed to acquisition and interpretation; critically revised manuscript; gave final approval; agrees to be accountable for all aspects of work ensuring integrity and accuracy.

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