EFFECT OF AIR-ABRASION AND ER:YAG LASER ON THE BOND STRENGTH BETWEEN THE METAL HOUSING OF AN OVERDENTURE ATTACHMENT SYSTEM AND THE HARD RELINING MATERIAL

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ABSTRACT

Objective: This study investigated the effect of air-abrasion and erbium:yttrium-aluminum-garnet (Er:YAG) laser treatments on push-out bond strength (PBS) between hard relining material and metal housing of an overdenture attachment system.
Materials and Methods: A total of 36 metal housings were randomly divided into 3 subgroups according to surface pretreatments (n=12): Control (no surface treatment; C), air-abrasion (A), and Er:YAG laser (L). Surface roughness (Ra) of specimens was determined using a profilometer. One additional specimen per group was evaluated by scanning electron microscopy (SEM). The hard relining material was bonded to metal housings, and a PBS test was performed using a universal testing machine. Data were statistically analyzed using 1-way analysis of variance (ANOVA), Tukey's honestly significant difference (HSD), and Tamhane's T2 tests (α=.05).
Results: C and L groups showed the lowest and highest Ra values, respectively. The mean Ra of the A group was statistically different from the mean values of the C and L groups (P<.001). The L group showed higher PBS values than the C group (P<.05), whereas the A group exhibited statistically similar PBS values to both C and L groups (P>.05).
Conclusion: Air-abrasion did not significantly increase the bond strength between the metal housing and hard relining material. Er:YAG laser irradiation noticeably improved the PBS but caused surface microcracks.

Keywords: Air-abrasion; Er:YAG laser; hard relining material; metal housing; overdenture attachment system; push-out bond strength

ÖZET

Amaç: Bu çalışma kumlamanın ve erbium:yttrium-aluminum-garnet (Er:YAG) lazer işlemlerinin sert astar materyali ile overdenture sistemine ait metal kep arasındaki itme bağlanma dayanımına (PBS) etkisini incelemiştir.
Materyal ve Metot: Toplamda 36 metal kep yüzey işlemlerine göre 3 altgruba ayrıldı (n=12): Kontrol (yüzey işlemi yok; C), kumlama (A) ve Er:YAG lazer (L). Örneklerin yüzey pürüzlülüğü (Ra) profilometre kullanılarak belirlendi. Her gruptan birer ilave örnek taramalı elektron mikroskobu (SEM) ile değerlendirildi. Sert astar materyali metal keplere bağlandı ve PBS testi evrensel bir test cihazı kullanılarak uygulandı. Veriler tek yönlü varyans analizi (ANOVA), Tukey dürüstçe anlamlı fark (HSD) ve Tamhane T2 testleri kullanılarak istatistiksel olarak analiz edildi (α=.05).
Bulgu: C ve L grupları sırasıyla en düşük ve en yüksek Ra değerlerini gösterdi. A grubunun ortalama Ra değeri C ve L gruplarının ortalama değerlerinden istatistiksel olarak farklıydı (P<.001). L grubu C grubundan daha yüksek PBS değeri gösterirken (P<.05), A grubu C ve L grupları ile istatistiksel olarak benzer PBS değerleri sergiledi (P>.05).
Sonuç: Kumlama metal kep ile sert besleme materyali arasındaki bağlanma dayanımını önemli ölçüde artırmamıştır. Er:YAG lazer irradiasyonu PBS'yi önemli ölçüde artırmış, ancak önemli yüzey çatlaklarına sebep olmuştur.

Anahtar Kelimeler: Er:YAG lazer; itme bağlanma dayanımı; kumlama; metal kep; overdenture ataşman sistemi; sert astar materyali

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INTRODUCTION

Due to prolonged life expectancy worldwide and increased tooth loss with age, prosthetic rehabilitation of elderly patients has gained importance. For a long time, conventional dentures have been the frequently applied treatment approach for edentulous patients (1, 2). However, stability and retention problems, particularly in lower total prostheses, create challenges in restoring speech and chewing functions in patients. Therefore, two implant-supported overdenture (ISO) prostheses were recommended instead of conventional prostheses for the rehabilitation of mandibular edentulism. It is well-known that these prostheses are superior in stability, retention, and chewing efficiency owing to implant support (2). Various designs such as ball, locator, magnet, and bar can be used in ISO attachments. Locator attachments are preferred due to their ease of use, variety in retention capacity, and compensation for the discrepancies between implant angulations (3). Moreover, studies show that these attachments can be used in cases of limited interocclusal distance (4). Locator systems generally consist of an abutment, a metal housing containing a black processing insert, and various color inserts with different retention levels (5). These attachments can be connected to the prosthesis using the direct method (in the mouth) or the indirect method (in the laboratory environment). Although the indirect technique has several advantages, such as reduced chairside time and reduced contact with acrylic monomer, possible inaccuracies resulting from implant-level impression may adversely affect the compatibility between the retaining system elements. Conversely, it is easier to ensure adaptation between the prosthesis and retaining parts in the direct method. This method can be performed by applying autopolymerizing resin to the prepared spaces in dentures for attachments (6). Nevertheless, debonding of the metal housing from the denture base is an important complication of these systems. Besides, adhesion failure may lead to undesirable gaps between the orientation material and the housing, resulting in microleakage and discoloration (7). Improving the bond strength between the metal housing and the hard relining material is essential to overcome this problem. Air-borne particle abrasion and laser irradiations are frequently applied pretreatments for various dental materials to increase the bonding area and strengthen the micromechanical connection. Several studies have reported that erbium:yttrium-aluminum-garnet (Er:YAG) laser irradiation and air-abrasion processes can affect the surface roughness of metal alloys and their bonding performance (8-10). However, there is no clear information on the effects of air-abrasion and Er:YAG laser treatments on the surface properties and bond strength of metal housing to hard relining material. Therefore, this study aimed to investigate the effect of air-particle abrasion using aluminum oxide particles and Er:YAG laser treatment on the bonding between the hard relining material and the metal housing of an implant overdenture attachment system. The null hypotheses of the study were that air-abrasion and Er:YAG laser treatments would not affect the 1) surface roughness (Ra) and 2) push-out bond strength (PBS) between the metal housing and hard relining material.

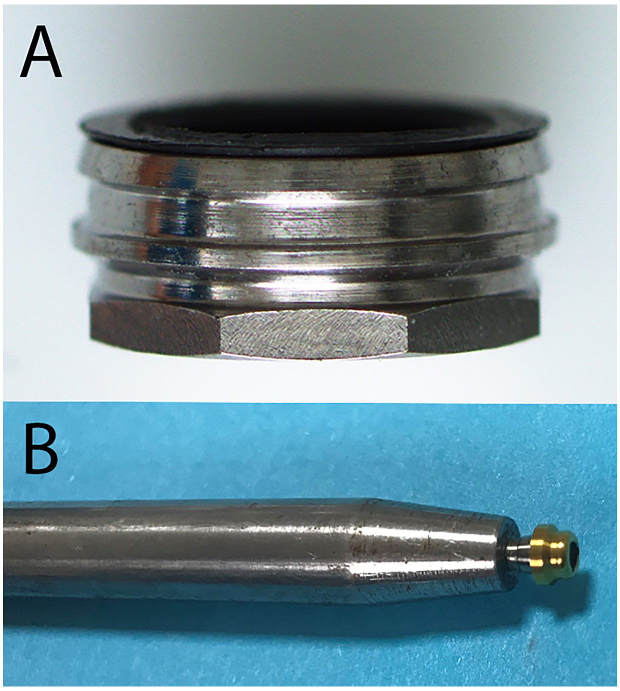

Figure 1: A) Metal housing of overdenture attachment system B) Custom-made test apparatus and abutment

MATERIALS AND METHODS

Surface treatments

A total of 36 metal housings (Figure 1A) with black processing inserts belonging to an overdenture attachment system (Kerator, KJ Meditech Co. Ltd, Gwang-Ju, Korea) were randomly divided into 3 subgroups according to surface pretreatments, as follows: Control (C): No treatment was applied. Laser treatment (L): The surfaces of the metal housings were irradiated using Er: YAG laser (Lightwalker DT, Fotona, Ljubljana, Slovenia) at a wavelength of 2940 nm using a special non-contact handpiece (R02) from 1 mm distance. The lateral surfaces of the metal housings were scanned for 20 s, and the flat surfaces were entirely scanned for 10 s under water- and air-cooling. The laser parameters applied were energy: 500 mJ, power: 5 W, frequency (pulse/s): 10 Hz, and SP mode (300 µs; pulse width). Air-abrasion (A): A sandblasting machine (Rotaks, Rotaks-Dent, İstanbul, Turkey) was used for air-abrasion. Sample surfaces were air-abraded using 50 µm aluminum oxide (Al2O3) particles (Mega Strahlkorund, Megadental GmbH, Budingen, Germany) under 2.5 bar pressure from a 15 mm distance. All the lateral surfaces of the samples were treated for 20 s, and the flat surfaces were air-abraded for 10 s. All surface treatments were performed by a single experienced researcher (Y.O.). After surface treatment, all specimens were ultrasonically cleaned (Cleanex 2801, Everest Elektromekanik, İstanbul, Turkey) in distilled water for 10 min.

Evaluation of surface roughness (Ra)

A surface profilometer (Surftest SJ-210, Mitutoyo Corp., Kanagawa, Japan) was used for Ra measurements. A total

Table 1: Results of the statistical analysis of surface roughness (Ra; µm)

	Mean ± SD *	Min	Max	95% CI
Control	0.41 ± 0.04A	0.34	0.47	0.38 – 0.43
Air-abrasion	1.32 ± 0.07B	1.22	1.42	1.28 – 1.36
Laser	1.87 ± 0.16C	1.60	2.13	1.77 – 1.98

SD: Standard deviation, CI: Confidence Interval
**The groups with different superscript letters are significantly different (Tamhane's T2; p<.05)*

of 6 readings in different directions (2 horizontal, 2 perpendicular, and 2 oblique) were recorded on the flat surfaces of metal housings, using a constant measurement speed of 0.5 mm/s and a cut-off value of λc=0.25 mm. The average value of those 6 readings was accepted as a final Ra score for each sample. The device was recalibrated after measurements for every 5 specimens.

Scanning electron microscopy (SEM)
One additional sample per group underwent SEM evaluation. First, the specimens were gold-sputter-coated (Quorum Q150R ES, Quorum Technologies, East Grinstead, UK), and subsequently SEM (EVO LS-10, Carl Zeiss, UK) images were captured from flat surfaces under ×100, ×500, and ×2000 magnifications at 25 kV.

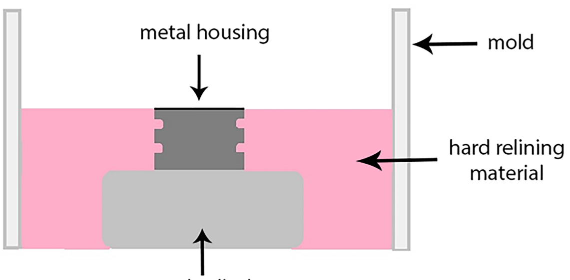

Figure 2: Schematic representation of bonding procedure

Bonding and push-out bond strength (PBS) test procedures
A schematic representation of the bonding procedure is presented in Figure 2. Lateral sides of 10-mm diameter metal cylinders were isolated with a thin layer of wax and placed into a mold possessing a hole with a diameter of 18 mm. Metal housings were placed centrally on this metal cylinder with the flat surfaces facing down. The hard relining material (Ufigel Hard, Voco Gmbh, Cuxhaven, Germany) was mixed according to the manufacturer's recommended ratio of 1 ml liquid per 3 ml powder and applied into the mold until the lateral surfaces of housings were fully covered with the relining material. The metal cylinders and molds were gently removed after the setting of relining material. The bonded specimens were held in water at 40 °C for 3 min, as described by the manufacturer. The abutment was screwed to a custom-made apparatus (Figure 1B) and mounted to a universal testing device (Lloyd LRX, Lloyd Instruments, Hampshire, UK). The abutment was placed into the black inserts, and a force was applied with a constant crosshead speed of 1 mm/min until failure occurred. PBS values were then recorded in Newtons.

Statistical Analysis
Statistical analyses were conducted using computer software (SPSS v.24, IBM, Chicago, IL, USA) by applying a significance level of α=.05. Normality of the data was assessed using Shapiro-Wilk test. The homogeneity of variances was evaluated using Levene test. One-way analysis of variance (ANOVA) followed by Tukey's HSD (for homogenous variances) or Tamhane's T2 tests (for non-homogenous variances) were used for group comparisons. The relationship between the Ra and PBS variables was assessed using Pearson correlation analysis.

RESULTS

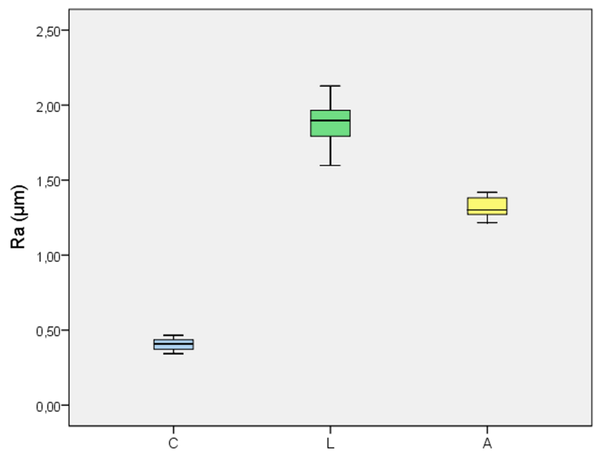

Figure 3: Box-plot graph comprising the Ra (μm) data of subgroups

Surface roughness (Ra)
One-way ANOVA revealed significant differences among the Ra values of experimental groups (F=625.754, P<.001). Figure 3 shows the distribution of Ra data according to subgroups as a box-plot graph. The statistical results are summarized in Table 1. C and L groups showed the lowest and the highest Ra values, respectively (P<.001). The mean Ra of the A group was significantly different from other groups (P<.001).

Table 2: Results of the statistical analysis of PBS (N)

	Mean ± SD *	**Min**	**Max**	**95% CI**
Control	488.50 ± 69.39 A	374.43	641.07	444.42 – 532.59
Air-abrasion	519.39 ± 79.47 AB	411.40	679.65	468.90 – 569.88
Laser	596.64 ± 102.46 B	439.58	794.78	531.54 – 661.74

SD: Standard deviation, CI: Confidence Interval, PBS: Push-out bond strength
**The groups with the same superscript letters are not significantly different (Tukey's HSD; p>.05))*

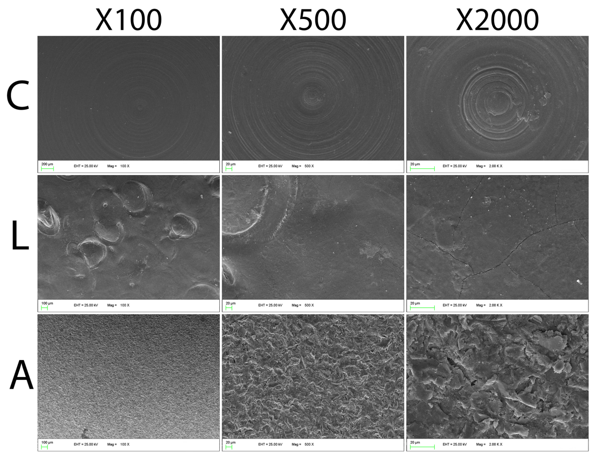

Figure 4: SEM images of metal housings

SEM evaluation
The captured images by SEM are presented in Figure 4. In concordance with the Ra results, the C group showed smoother surfaces than the others. Air-abraded specimens exhibited homogeneously abraded microporous surfaces, while laser-irradiated specimens showed a rough and irregular surface accompanied by microcracks.

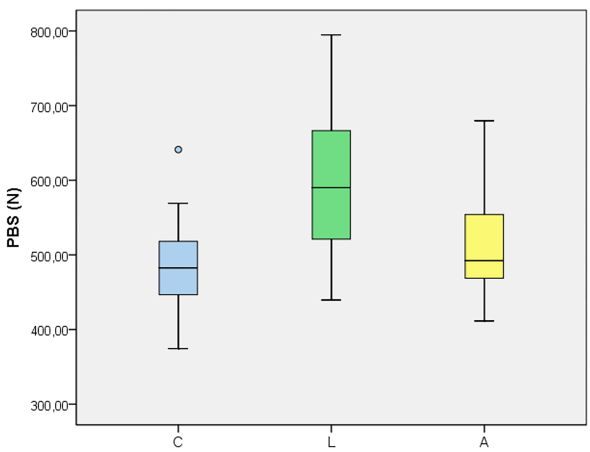

Figure 5: Box-plot graph comprising the PBS (N) data of subgroups

Push-out bond strength (PBS)
According to 1-way ANOVA, there were statistically significant differences for PBS of subgroups (F=5.164, P=.011). The distribution of PBS data is represented in Figure 5 based on the groups, and statistical comparisons are listed in Table 2. The L group showed higher mean PBS than the C group (P=.01), whereas the difference between the C and A groups was statistically insignificant (P=.65). Although the L group exhibited higher PBS than the A group, this difference was insignificant (P=.081). In addition, based on the Pearson correlation analysis (r=0.444, P=.007), a meaningful positive correlation was found between the dependent variables (Ra and PBS).

DISCUSSION

The present study examined the impact of different surface treatments, namely air-abrasion and Er:YAG laser, on the Ra and PBS of overdenture attachment housings. The first null hypothesis was rejected as significant differences in Ra were observed among all test groups. Furthermore, laser irradiation significantly increased the PBS, whereas air-abrasion did not produce any statistically significant difference. Thus, the second null hypothesis was partially rejected. The bonding performance of metal components to denture base materials is a key factor for the longevity of dental prostheses (11). Debonding of metal housings from the denture base is a common clinical failure for ISOs with locator attachment systems, compromising chewing function. Thus, it is critical to establish a strong and durable bond between the denture base resin and metal housing (12). A previous report showed that air-abrasion and Er:YAG laser treatments can increase the bond strength of metal alloy to acrylic resin (13). However, to our knowledge, the effects of pretreatments (mentioned above) on the bond strength between metal housings of overdenture attachment systems and hard relining materials have not yet been investigated. In the present study, Ra values were higher in both A and L groups than in the C group. This result is supported by SEM images, which show increased surface microporosity after air-abrasion and laser-induced distinct surface depressions. Besides, laser treatment was more effective in increasing Ra values than air-abrasion. This result contradicts the study of Kunt et al. (8), in which the base metal alloy was irradiated with 500 mJ Er:YAG laser and air-abraded using 50 µm $Al2O3$. The same authors reported that Er:YAG laser irradiation resulted in shallow erosions, and air-abrasion led to higher roughness values. Even if the parameters of the treatments are similar, the differences among the studies can be attributed to the use of different types of metals. Further studies evaluating the roughness of metal housings of overdenture systems are needed since the reports on this area are limited in the dental literature. The effects of laser treatments on the bonding efficacy of titanium surfaces are poorly investigated in the literature. In the study by Venkat et al. (14), Nd: YAG laser treatment and air-abrasion were performed on titanium abutment surfaces. The authors reported that laser treatment and air-abrasion with 110 µm Al2O3 particles at 2.8 bar markedly improved the retention of acrylic crowns. A previous report showed that the alumina particle size selected for air-abrasion can significantly increase titanium-acrylic resin bond durability (15). In the current study, air abrasion was implemented using 50 µm Al2O3 particles, as applied in other studies (11, 16). Another research by Ishii et al. (17) investigated the effects of air-abrasion on bond strength between acrylic resin and different metal alloys. Their results revealed that air-abrasion produced a noticeable increase in the bond strength, regardless of the metal alloy type, which complies with the study by Duran et al. (13). Contrary to the results of these studies, air-abrasion performed in the current study did not significantly increase bond strength values. This finding can be explained by the macromechanical retention owing to undercuts on the axial walls of the housing. Thus, the microporosities created by air-abrasion might have substantially less impact in improving bond strength than the axial undercuts of the metal housing. Conversely, the L group showed statistically higher PBS values than the control. However, it is noteworthy that substantial microcracks were observed in SEM images after laser treatment, which may adversely affect mechanical properties and long-term success. Therefore, Er:YAG laser treatment with the parameters applied in this study is not recommended to modify the surface of metal housings. Future studies should examine the effects of Er:YAG laser with different parameters. Besides, although the mean PBS for the L group was higher than that for the A group, this difference was statistically insignificant. This result was consistent with a recent study in which fiber laser and air-abrasion using 50 µm Al2O3 particles was applied to titanium surfaces for acrylic resin bonding (18). Although a pull-out test design might help imitate the intraoral forces that cause debonding of the metal housing from the denture base, the push-out test was preferred (12) due to technique sensitivity and difficulties in establishing a pull-out test design. This study tested one type of metal housing. Therefore, future research should examine metal housings with different designs. Some studies reported that thermocycling decreases the bond strength between metal alloys and denture base materials (19, 20). Although the present study focused on the effects of surface treatments on initial bond strength between the metal housing and hard relining material, further studies should investigate bond durability by applying long-term aging conditions. Additional investigations are necessary to evaluate the bond strength of pretreated metal housings to heat-polymerized denture base materials. In addition, further studies evaluating the effects of different types of lasers and different laser parameters on the bond strength between metal housing and hard relining material are needed.

CONCLUSION

Air-abrasion did not significantly improve the bonding performance of hard relining material to the overdenture attachment system's metal housing. Conversely, Er:YAG laser irradiation markedly increased the bond strength values but caused significant surface microcracks. Thus, the surface pretreatments used in this study cannot be recommended for clinical use.

Ethics

This article does not contain any studies with human participants or animals performed by any of the authors.

Authorship Contributions:

Surgical and Medical Practices: Y.O., G.A.D., Concept: Y.O., G.A.D., Design: Y.O., G.A.D. Data Collection or Processing: Y.O., G.A.D. Analysis or Interpretation: H.Ş., Y.O., Literature Search: H.Ş., G.A.D., Writing: H.Ş., Y.O.

Declaration of competing interest:

No conflict of interest was declared by the authors.

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