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Effect of Erbium:YAG Laser Recycling on Mechanical Characteristics of Retrieved Orthodontic Mini-screws

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Abstract

Introduction: This study aimed to evaluate the influence of two recycling methods on the mechanical and surface characteristics of orthodontic mini-screws.

Methods: Thirty-six retrieved mini-screws were randomly classified into two equal groups. In the first group (laser recycled group (LG)), the Er:YAG laser (2940 nm, 5.5 W, 275 mJ, perpendicular to the mini-screws at a distance of 7-10 mm, 25 s) was used to recycle mini-screws. In the second group (phosphoric acid and sodium hypochlorite recycled group (ASG)), the mini-screws were kept in 37% phosphoric acid gel (10 minutes) and then placed in 5.25% sodium hypochlorite for 30 minutes. Eighteen new mini-screws were selected as the control group (CG). Maximum insertion torque (MIT), maximum removal torque (MRT), and fracture torque (FT) of all mini-screws were measured. A sample from each group was examined for the surface changes of the mini-screw and tissue remnants under a scanning electron microscope (SEM).

Results: The mean MIT was significantly higher in both LG and ASG groups than the CG ($P<0.001$ and $P=0.002$, respectively). However, no significant difference was shown between the LG and ASG groups. The mean values of MRT and FT showed no significant difference between the groups. The amount of tissue remnants in the ASG group was significantly higher than that in the LG group. The evidence of porosity and corrosion was observed on the ASG mini-screw surface, and there was an increase in roughness on the LG mini-screw surface.

Conclusion: The Er:YAG laser recycling of mini-screws is a proper method causing minimum damage to the screw surface.

Keywords: Retrieved orthodontic mini-screw; Recycling; Biomechanical characteristics; Surface characteristics.

Introduction

Anchorage provision is one of the main issues in orthodontics. Today, orthodontic mini-screws are used to reinforce anchorage due to their small size, the possibility of their placement in different parts of the mouth, less discomfort for patients, no need for their cooperation, the possibility of immediate loading, and no need for surgery.[1,2] Although the mini-screw placement protocol is relatively simple, under some conditions, due to tissue inflammation, mobility, obstruction of tooth movement and anatomical limitations such as proximity to roots, nerves, and blood vessels' relocation may be required. Using a new mini-screw in these cases increases treatment costs. Screw recycling eliminates additional costs, enhances clinical usage, and improves orthodontic treatment.[3-5] However, this clinical process requires a precise recycling process to preserve the structural integrity and mechanical properties of the mini-screws. Before reusing the mini-screws, an effective cleaning and sterilization procedure is needed to eliminate any contamination and infection. Various studies have indicated no adverse effect of autoclave sterilization on the mechanical characteristics and initial stability of mini-screws.[3,6-8] Different mini-screw cleaning processes are electrolytic, ultrasonic, sandblasting, and chemical methods.[7] The effect of these different mini-screw recycling methods on their mechanical and surface properties has been investigated in several studies.[1,3,7,9] However, to the best of our knowledge, no study has evaluated the efficacy of laser application in mini-screw recycling.

A laser is used in orthodontics for various purposes, including enamel etching, pain relief, accelerated orthodontic tooth movement, and mini-screw stabilization.[10] The present study aimed to investigate the effect of two orthodontic mini-screw recycling methods on their mechanical and surface properties.

Materials and Methods

In the present study, 36 titanium mini-screws (Jeil Medical Corporation, Korea) with a length of 8 mm and a diameter of 1.6 mm were located in the maxillary alveolar bone between the first molar and the second premolar for anchorage arrangements for six months. After

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removing the mini-screws from the oral environment, they were placed in distilled water until the beginning of the laboratory processes, as distilled water was changed daily. These mini-screws were randomly classified into two equal groups, and the third group (CG) consisted of 18 new mini-screws with characteristics similar to the experimental groups.

Recycling Process

The mini-screws in the first group (LG) were first washed using 10 ml of distilled water and dried by gentle air pressure for 5 seconds. Moreover, an Er:YAG laser (Fotona – 1210 Ljubijana, Slovenia) with a wavelength of 2940 nm operated in a pulse wave mode (medium short pulse) with 5.5 W output power with air and water cooling spray was used. The laser irradiation was performed at a distance of 7-10 mm perpendicular to the mini-screws (Figure 1a). In the second group (ASG), the mini-screws were washed, dried, and then immersed in 37% phosphoric acid gel for 10 minutes. They were washed, dried, and placed in 10 mL of 5.25% sodium hypochlorite (NaOCl, Raga, Pakrood Co., Iran) for 30 minutes, followed by washing and drying once more (Figure 1b and c). The third group (CG) included 18 new mini-screws with the same characteristics as the experimental groups. As for the two experimental groups, these samples were washed and dried. Then all samples of the three groups were sterilized by autoclave (temperature 121 °C and 18 psi pressure) for 20 minutes.

Mechanical Characteristics

The digital torque tester (Imada Inc., Northbrook, USA) evaluated the mechanical properties of the mini-screws. The milling machine (Jamco, CM6241. 2010, and China) was applied to drive the mini-screws to eliminate eccentric movements and control the insertion speed, rotation, and depth. The torque tester was inserted into the milling machine, and the mini-screws were connected to the torque tester using a custom-made screwdriver. The complex was placed on the rotating part of the milling machine, and a 3 mm thick polycarbonate plate (Raychung, Taiwan) was positioned in its non-rotating part (Figure 2). The mini-screws were driven into the polycarbonate plate with a milling machine. The rotation speed of the machine was 45 rounds per minute (45 rpm). The insertion and removal speeds were compatible with the pitches of the mini-screws (0.9 mm/360° rotation). To prevent deviations from the mini-screw axial inclination during the insertion, holes with depths of 1 mm and diameters of 0.8 mm were predrilled in the polycarbonate plate with a distance of 10 mm. The removal and insertion torque tests were performed by driving the mini-screws perpendicular to the polycarbonate plate. The insertion depth was the same for all samples (7.5 mm). Maximum insertion and removal torque were then recorded (N.cm unit).

The insertion of the same mini-screws was performed into a 10 mm thick polycarbonate block to measure the fracture torque (FT). Maximum torque was recorded before breaking the mini-screws.

Surface Properties

To evaluate the morphological characteristics and changes of the mini-screw surface after the recycling process, a sample from each group was scanned by an electron microscope (SEM, VEGA, TSCAN) at different magnifications and 15 kV voltage. The samples were examined to discover any porosity, corrosion, roughness, morphological changes, tip angle of the mini-screw, and the amount of tissue residue on the surface of the mini-screw.

Statistical analysis

The statistical analysis of the collected data was performed with PASW® version 18 (SPSS Inc., IL, USA) using Kruskal-Wallis, Mann-Whitney, and one-way ANOVA tests. A $P<0.05$ was considered as the significance level.

Results

Mechanical Characteristics

Tables 1, 2, and 3 present the results of the torque experiments. The three groups showed significantly different mean maximum insertion torque (MIT) values ($P<0.001$). In both LG and ASG groups, the mean MIT was significantly higher than in the CG group ($P<0.001$ and $P=0.002$, respectively); however, no significant difference was found between the LG and ASG groups

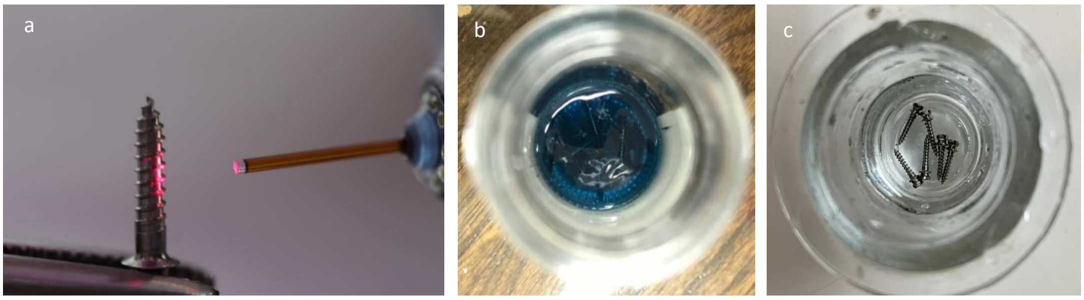

Figure 1. Images of Recycling Processes Used in the Study. **(a)** Er:YAG laser irradiation (mechanical cleaning). **(b)** immersion with 37% phosphoric acid (10 min; chemical cleaning). **(c)** immersion with 5.25% sodium hypochlorite (10 min; chemical cleaning)

Table 1. Mechanical Properties of New and Recycled Mini-screws

Groups	Number	Mean ± Standard Deviation		
		Insertion Torque	Removal Torque	Fracture Torque
CG	18	13.77 ± 0.68	17.43 ± 1.71	36.16 ± 2.04
LG	18	18.12 ± 2.63	17.20 ± 3.23	35.07 ± 3.83
ASG	18	17.37 ± 2.78	16.12 ± 2.58	35.42 ± 4.37
P value		< 0.001*	0.279	0.697

CG, control group; LG, laser group; ASG, phosphoric acid and sodium hypochlorite recycled group.
*Statistically significant ($P < 0.05$). The torque unit is presented in N.cm.

Table 2. Comparison of Maximum Insertion Torque Between Groups (Mann-Whitney test)

Groups	CG	LG	ASG
CG	-	< 0.001*	0.002*
LG	< 0.001*	-	0.350
ASG	0.002*	0.350	-

CG, control group; LG, laser group; ASG, phosphoric acid and sodium hypochlorite recycled group.
* Statistically significant ($P < 0.05$).

Table 3. The Mean Value of MIT in All Groups

Groups	Mean ± Standard Deviation	95% Confidence Interval	
		Lower Bound	Upper Bound
CG	13.77 ± 0.68	13.43	14.11
LG	18.12 ± 2.63	16.81	19.43
ASG	17.37 ± 2.78	15.98	18.75

CG, control group; LG, laser group; ASG, phosphoric acid and sodium hypochlorite recycled group.
* Statistically significant ($P < 0.05$). The torque unit is presented in N.cm.

($P = 0.350$). The mean maximum removal torque (MRT) and FT showed no significant difference between the three groups ($P = 0.279$ and $P = 0.697$, respectively).

Surface Properties

In the lateral view of the mini-screws in SEM, on the surface of the ASG mini-screw, tissue remnants were seen as a black stain, while in the mini-screw surface of the LG, little or no stain was observed, which was similar to that of the CG group (Figure 3). Moreover, the tip angle of the ASG mini-screw was slightly blunter than the CG; however, the LG mini-screw was slightly sharper than the CG. Further, there was no evidence for the deformation and torsion of the mini-screw tips in either the ASG or LG

Figure 2. Torque Testing Setup (Milling Machine, Torque Tester, Custom-Made Screw Driver, Mini-screw and Polycarbonate Plate)

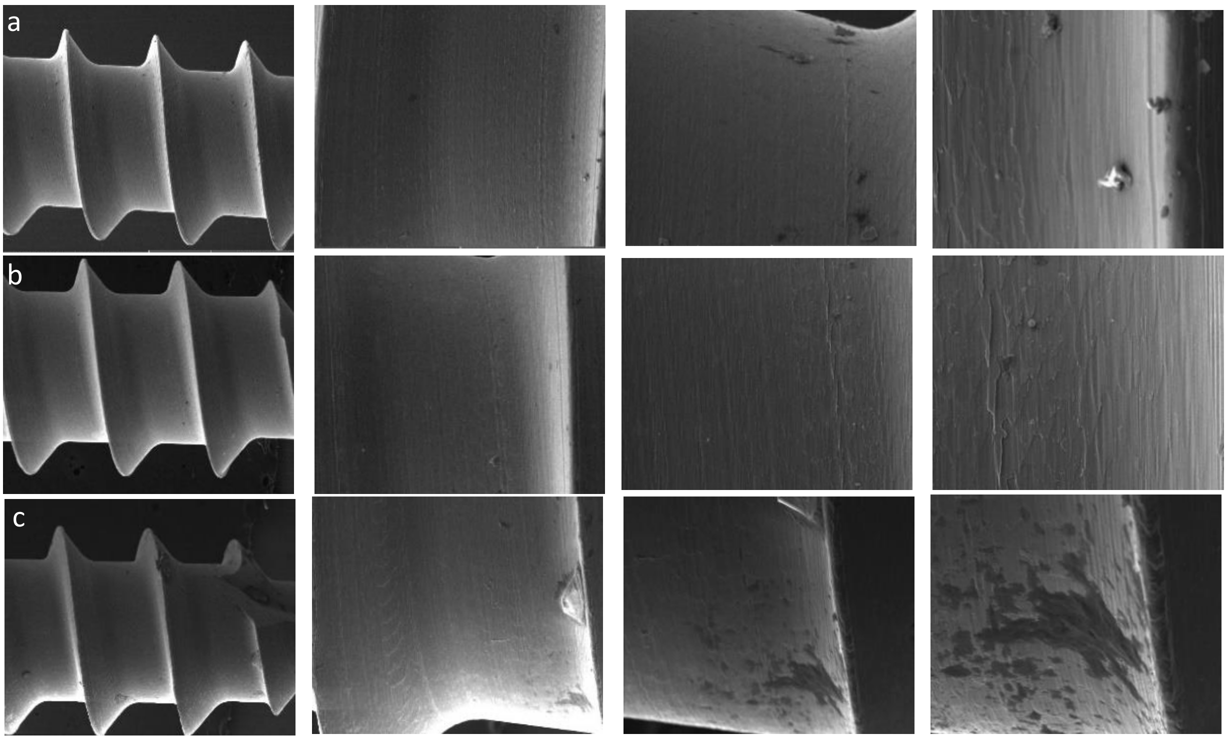

Figure 3. SEM Images of Lateral View of Recycled Mini-screw Along With a New Mini-screw as a Control. **(a)** new mini-screw. **(b)** laser recycled mini-screw. **(c)** phosphoric acid and sodium hypochlorite recycled mini-screw

groups (Figures 4 and 5).

The SEM observation of the tip of the mini-screws showed evidence of porosity at the surface of the ASG mini-screw (Figure 5C). However, there was no porosity in the LG mini-screw. Moreover, there was a slight increase in surface roughness in the mini-screw surface of the LG compared to that of the CG (Figure 5B). The tip angle of CG, LG, and ASG mini-screws were 46°, 42°, and 51°, respectively (Figure 6).

Discussion

Mini-screws are sometimes discarded due to stability failure, which may happen within the first few days or months following placement. Likewise, some mini-screws are discarded due to the need for repositioning by orthodontic mechanics. Therefore, reusing the same mini-screws to reduce the number of mini-screws used during treatment has been considered by orthodontists.[7] To reuse the mini-screws, they should be recycled. The recycling process includes cleaning and sterilization stages.

Cleaning can be done either mechanically or chemically. In the present study, both mechanical and chemical methods were used. For chemical cleaning, 37% phosphoric acid and 5.25% sodium hypochlorite, which have been employed in other studies to clean mini-screws, were used.[1,3,9] Both materials are commonly available in clinics and are inexpensive and easy to work with. Due to its low pH, the acid can remove the mineral part of the bone left on the mini-screw, and sodium hypochlorite can dissolve the organic remnant tissues. Therefore,

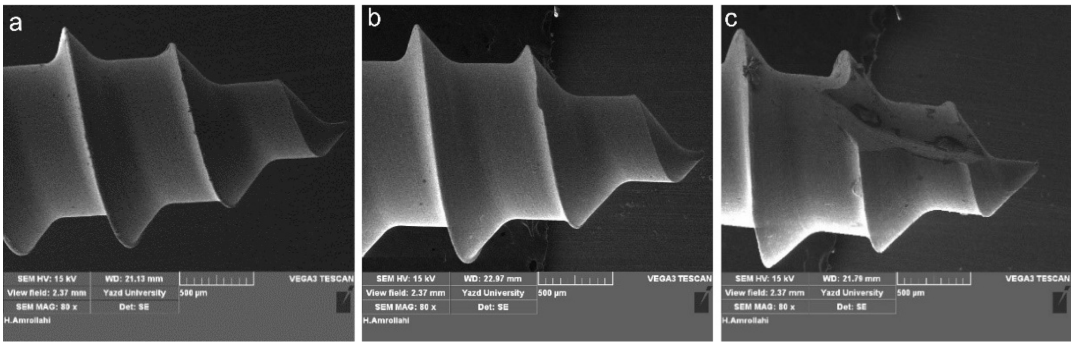

Figure 4. SEM Images of the Tips of Recycled Mini-screw Along With a New Mini-screw as a Control. **(a)** new mini-screw. **(b)** laser recycled mini-screw. **(c)** phosphoric acid and sodium hypochlorite recycled mini-screw

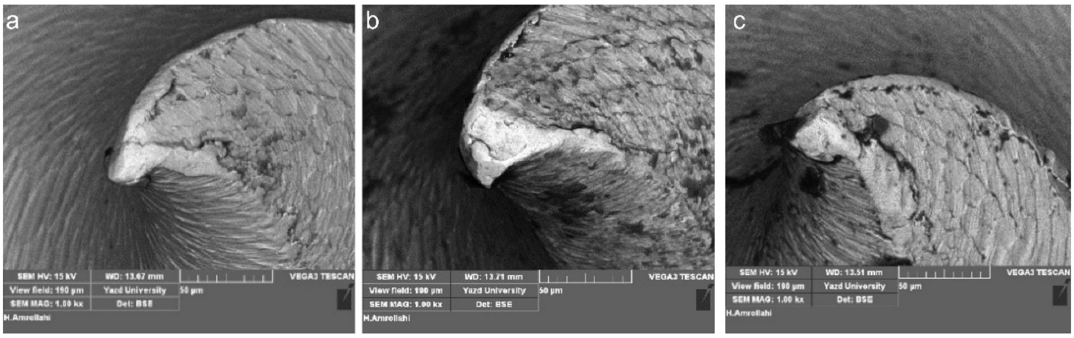

Figure 5. SEM Images of the Tips of Recycled Mini-screw Along With a New Mini-screw as a Control. **(a)** new mini-screw. **(b)** laser recycled mini-screw. **(c)** phosphoric acid and sodium hypochlorite recycled mini-screw

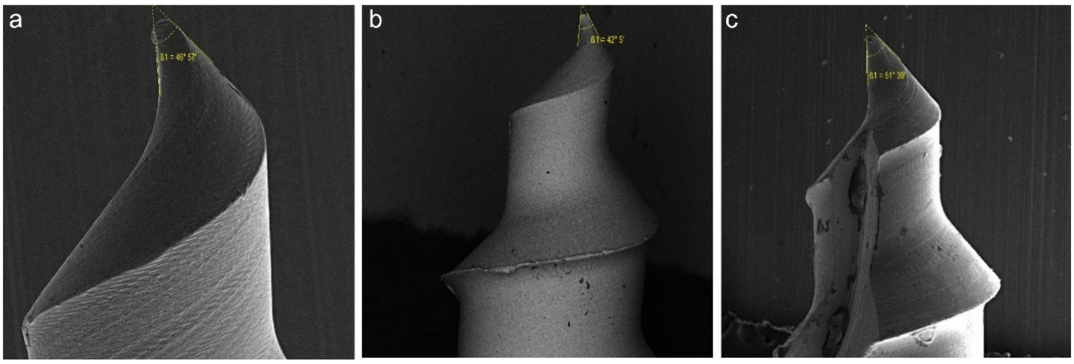

Figure 6. SEM Images of the Tip Angle of Recycled Mini-screw Along With a New Mini-screw as a Control. **(a)** new mini-screw. **(b)** laser recycled mini-screw. **(c)** phosphoric acid and sodium hypochlorite recycled mini-screw

according to many studies, both materials together can remove inorganic and organic materials on the mini-screw without degrading the titanium surface and they are considered suitable alternatives for recycling titanium mini-screws.[1,3,9]

Another cleaning method in the present study was a mechanical method using Er:YAG laser irradiation with a wavelength of 2940 nm to clean the mini-screws and remove tissue remnants. In several studies, the Er:YAG laser has been used to recondition debonded brackets and has been shown to increase the shear bond strength highly similar to new brackets.[10,11] Kreisler et al[12] evaluated the surface of implants treated with the Er:YAG laser and found that this laser had the potential to remove toxic bacterial components, perform the reliable decontamination of the implant without damaging its surface, and produce cell growth similar to sterile implants.

The last step of recycling is sterilization, which prevents the proliferation of microorganisms. On the other hand, high temperature during the re-sterilization of mini-screws denatures possible residual proteins and reduces their risk of allergenicity, if present.[1,9] Sterilization methods are autoclaving, plasma oxygen therapy, gamma irradiation, and ultraviolet irradiation. In the present study, autoclaving, which is the most common method and the gold standard of sterilization processes, was used for sterilization.[1,13] Several studies have indicated that autoclave sterilization has no negative effects on the strength and FT of bone screws.[7,9,14,15] Adelson et al[14] showed that up to 50 times, autoclave sterilization had no effect on the torque and strength of the mini-screws. Mattos et al[15] observed no significant change in the fracture resistance of autoclaved mini-screws. However, some studies have reported that autoclaving alone cannot eliminate the contamination of equipment if adequate cleaning is not performed before sterilization.[16] Accordingly, adequate cleaning is necessary before sterilization.

It should be noted that recycled mini-screws can be used if their structural integrity and mechanical properties are maintained after recycling. The effect of two mini-screw recycling processes on MIT, MRT, and FT has been investigated to evaluate the mechanical properties.

In the present study, to increase the precision of torque testing experiments, a milling machine was used to drive the mini-screws. Furthermore, a polycarbonate plate with mechanical properties similar to a natural bone was used to remove the anatomical variations in bone thickness and density, equalize the conditions for all specimens, and insert the mini-screws. The polycarbonate plate is soft enough to allow mini-screw insertion and, at the same time, has enough resistance until the fracture of the mini-screw.[3,9,17-19]

MIT is the maximum torque recorded during mini-screw insertion due to the friction between the bone and the screw threads, and it is used as a reliable parameter to determine the initial stability of the mini-screw.[3,20] Previous studies have shown that increasing MIT can reduce the micro-movement of the mini-screws and increase its success. However, additional stress on the bone can cause local necrosis and prevent osteointegration and secondary stability.[21]

In the present study, the MIT of mini-screws in the CG group (as-received) was significantly less than in the two case groups. However, no significant difference was found between the two recycled groups of LG and ASG. The increase in insertion torque in the recycling groups could be due to blunt threads. It can be predicted with 95% confidence that after the laser recycling process, the MIT compared to the CG is at least 3.4 N.cm and at most 5.3 N.cm. After the acid recycling process, it would increase at least by 2.5 N.cm and at most by 4.6 N.cm (Table 3). This amount is clinically negligible and does not make the placement of the mini-screw problematic, thereby not increasing the risk of failure. On the other hand, because the average insertion torque of the recycled mini-screws is less than their average FT in each group, this increase in the insertion torque of the recycled mini-screws will not make the mini-screw break during the insertion.

In a systematic review study by Meursinge Reynders et al,[21] a specific amount of MIT was not recommended for orthodontic mini-screws. However, several clinical papers have presented the maximum amount of insertion torque in the range of 5-10 N.cm as the gold standard.[22-24] On the other hand, Chaddad et al[25] reported that mini-screws with a torque > 15 N.cm had a higher survival rate. In the present study, the mean MITs of the mini-screws in the LG and ASG groups were 18.12 and 17.37 N.cm, respectively, which is consistent with the torque proposed by Chaddad et al (> 15 N.cm).[25] Moreover, in an in vitro study, Wilmes et al[26] observed the break of mini-screws at torque levels > 23 N.cm and recommended that the MIT should be 20 N.cm; the mean MIT in the present study groups was below this value. It should also be noted that the reason for the higher insertion torque of the mini-screws in our study compared to the study by Motoyoshi et al,[22] who reported suitable insertion torque to increase success rate as 5-10 N.cm, can be attributed to the size of the pilot hole. The diameter and length of the pilot hole in their study (1.3 × 8 mm) were much larger than those of the pilot hole in the present study (0.8 × 1 mm), and the length of the pilot hole in that study was eight times as large as the length of the pilot hole in the present study. The pilot hole in the present study guided the placement of mini-screws only. Given that predrilling the pilot hole reduces the rate of MIT,[27] if the present study used the same pilot hole as in the previous study, the torque of the recycled mini-screws would be significantly reduced and was close to the range recommended in Motoyoshi and colleagues' study.[22] Further, Motoyoshi et al [22] considered insertion torque as the only determining factor for the success or failure of mini-screws. However, since their research was a clinical study, in addition to the amount of insertion torque, other variables may also contribute to the success rate of the mini-screws. The higher failure in the higher torque values in their study may be due to places where the insertion torque was higher (such as the posterior part of the mandible). These areas had more chewing forces and limited access to oral hygiene and were more difficult locations for mini-screw placement, all of which affected the success rate of mini-screws. Accordingly, in addition to the amount of insertion torque, other factors such as muscle function and traction, variety of orthodontic forces, and oral hygiene may play a role in the success rate of mini-screws.[28]

The mean values of MRT in the CG, LG, and ASG groups were 17.43, 17.20, and 16.12 N.cm, respectively, and no significant difference was found between the three experimental groups ($P=0.279$), indicating that the recycling of mini-screws had no adverse effect on MRT and clinical stability, which was in agreement with other studies.[3, 9]

The mean values of FT in the CG, LG, and ASG groups were 36.16, 35.07, and 35.42 N.cm, respectively, and no significant difference was found between the three groups. These findings are in line with those reported by Noorollahian et al[3,9] and Estelita et al.[7] Defino et al[29] also observed that the mechanical properties of screws were affected only after three insertions. Laboratory studies have suggested that torque of ≥ 23 N.cm is needed for the mini-screw to break.[17,26] As observed, the FT level in all three groups was >23 N.cm and covered the recommended safe margin.

In addition to structural strength, the reuse process requires a suitable recycling protocol to create a reconditioned surface free of any residues of organic matter, microorganisms, or corrosive materials. In examining recycled and new mini-screws by SEM, the amount of tissue residues in the mini-screw recycled by 37% phosphoric acid and 5.25% sodium hypochlorite was higher than that of the mini-screw recycled by the Er:YAG laser, implying that the laser is more effective than phosphoric acid and sodium hypochlorite in removing tissue residues on the surface of the mini-screw. Although some studies[1,9] stated that phosphoric acid and sodium hypochlorite had no destructive effect on the surface of titanium, in the present study, porosity was observed on the surface of the ASG mini-screw, indicating titanium corrosion due to phosphoric acid and sodium hypochlorite; however, no porosity was observed on the surface of the screw recycled by the laser. Moreover, Galeotti et al[30] showed that mini-screws stored at pH 4 exhibited a significant cytotoxic response. This was probably due to the release of metal ions from the mini-screws. Furthermore, the roughness of the LG mini-screw slightly increased compared to that of the CG, which can increase the mini-screw osteointegration.[31] Likewise, measuring the angle of the mini-screw tip showed that the mini-screw tip of the ASG was slightly blunted, while the mini-screw tip of the LG was slightly sharper. Hence, in the SEM observation, the mini-screw recycled by the Er:YAG laser was better.

Conclusion

1. The MIT of mini-screws recycled by the Er:YAG laser and mini-screws recycled by 37% phosphoric acid and 5.25% sodium hypochlorite were not significantly different; however, they were significantly higher than that of the CG. This is while the MRT and FT mini-screws of the three groups were not significantly different.

2. The morphological features and surface characteristics of the mini-screw recycled by the Er:YAG laser were significantly better than the mini-screw recycled by 37% phosphoric acid and 5.25% sodium hypochlorite.

Authors' Contribution

Conceptualization: Soghra Yassaei.
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Formal analysis: Soqra Yassaei, Atie Behrouzirad.
Funding acquisition: Soghra Yassaei, Atie Behrouzirad.
Investigation: Soghra Yassaei, Hossein Aghili, Atie Behrouzirad.
Methodology: Soghra Yassaei, Hossein Aghili, Atie Behrouzirad.
Project administration: Soghra Yassaei, Hossein Aghili, Atie Behrouzirad.
Resources: Soghra Yassaei, Hossein Aghili, Atie Behrouzirad.
Software: Atie Behrouzirad.
Supervision: Soghra Yassaei, Hossein Aghili, Atie Behrouzirad.
Validation: Soghra Yassaei, Hossein Aghili.
Visualization: Soghra Yassaei, Hossein Aghili, Atie Behrouzirad.
Writing–original draft: Atie Behrouzirad.
Writing–review & editing: Soghra Yassaei, Hossein Aghili, Atie Behrouzirad.

Competing Interests

None.

Ethical Approval

This research was approved by the Ethics Committee and the Research Vice Chancellor of Shahid Sadoughi University of Medical Sciences (Code: IR.SSU.REC.1399.138).

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