Recycling stainless steel orthodontic brackets with Er:YAG laser – An environmental scanning electron microscope and shear bond strength study

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ABSTRACT

Aim: To determine the efficiency of erbium: Yttrium aluminum garnet (Er:YAG) laser with Environmental Scanning Electron Microscope (ESEM) and shear bond strength analysis as a method of recycling stainless steel orthodontic brackets and compare with other methods of recycling.

Materials and Methods: Eighty samples of extracted premolar teeth bonded to SS brackets were tested for rebonded shear bond strength after recycling by four methods and compared with a control group of 20 samples. These 80 samples were randomized into four groups which were recycled by four methods, namely, sandblasting, thermal method, adhesive grinding by tungsten carbide bur, and Er: YAG laser method. After recycling, ESEM and shear bond strength analysis were used to analyze the efficiency of the recycling methods

Results: Er: YAG laser group was found to be having the greatest bond strength among the recycled brackets (8.33±2.51 followed by the sandblasting at 6.12±1.12 MPa, thermal and electropolishing at 4.44±0.95 MPa, and lastly the adhesive grinding method at 3.08±1.07 MPa. The shear bond strength of Er: YAG laser group was found to be having no statistically significant difference with that of the control group (P>0.05 and had statistical signifance with sandblasting, thermal and electropolishing and adhesive grinding groups at P<0.001. ESEM analysis showed complete removal of adhesive from the brackets recycled with Er: YAG laser which mimicked that of the control group.

Conclusion: Er: YAG laser (2940 nm) was found to be the most efficient method for recycling, followed by the sandblasting, thermal, and the tungsten carbide methods, which had the least shear bond strength value and is not fit for clinical usage.

Key words: Bond strength, erbium: yttrium aluminum garnet laser, environmental scanning electron microscope, orthodontic brackets, recycling

INTRODUCTION

Bonding in orthodontics has undergone several facelifts since its inception into orthodontics. The bonding of orthodontic attachments to etched enamel surfaces with dental resins was introduced by Buoncore in 1955.[1]

One of the commonly faced problems during treatment is of bracket dislodgement.[2] The clinician can recycle or re-condition these brackets for reuse.[3]

There are many options available for recycling orthodontic brackets. Some of the in-house methods such as thermal (direct flaming only[3] or Buchman method[4]) or mechanical methods (sandblasting,[3,5-11] green stone,[3,12,13] and tungsten carbide bur[14]) offer a more realistic, simple, and cost-effective alternative.

The first commercially available lasers were suitable for soft-tissue treatments, especially in periodontics.[15] When these lasers were used on dental hard tissues, the result was major thermal damage rendering these lasers unsuitable for hard-tissue treatments.[16-18] The development of erbium: Yttrium

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aluminum garnet (Er: YAG) laser[15,16,18,19] and, more recently, the erbium, chromium: Yttrium scandium gallium garnet (Er, Cr: YSGG) laser[20] permits ablation in both soft and hard tissues without any thermal side effects.[15,18] Studies have demonstrated the effect of lasers on debonding ceramic brackets,[21-23] etching enamel,[24,25] curing adhesive,[26-28] and more recently, in reducing pain in orthodontics.[29]

This study aimed at evaluating the effectiveness of Er: YAG laser along with other methods of in-house recycling such as sandblasting, thermal and electropolishing and adhesive grinding) for reconditioning stainless steel brackets.

MATERIALS AND METHODS

Ethical clearance was taken before the study was carried out on 100 non-carious premolar teeth, extracted as a part of orthodontic treatment from patients in the age group between 12 and 20 years. The teeth were used within 1 month of extraction and those with any pathology were discarded. Extracted teeth were then cleansed, and after careful debridement, the teeth were stored in saline at room temperature.

These 100 teeth were then mounted on acrylic blocks with only their crowns exposed Figure 1. The acrylic blocks were color-coded and divided into five groups with 20 teeth in each group. They were then bonded with premolar metal brackets (0.022 slot, Gemini series; 3M Unitek, Monrovia, CA, USA) using Transbond XT light cure composite (3M Unitek, Monrovia, CA, USA).

The bonding procedure was performed as per the manufacturer's instructions.

The teeth were then immersed in artificial saliva for 24 h prior to testing, so that the pH of the oral environment could be simulated.

The groups were designated as follows:

- Group I, control group (20 teeth).
- Group II, comprising 20 teeth, which were to be recycled by sandblasting method.
- Group III, comprising 20 teeth, which were to be recycled by thermal method.
- Group IV, comprising 20 teeth, which were to be recycled by the adhesive grinding method.
- Group V, comprising 20 teeth, which were to be recycled by Er: YAG laser.

Control Group (Group I)

Group I samples were tested on the Lloyd universal testing machine (model LR 100, AMETEK Measurement and Calibration Technologies, West Sussex, UK) [Figure 2] for their shear bond strength (SBS). The cross-head speed was set at 1 mm/min.[14] Load required for debonding each bracket in megapascals (MPa) was recorded and the SBS value was obtained.

Eighty brackets in groups II, III, IV, and V were then debonded using debonding pliers,[14] and after debonding each bracket, the corresponding acrylic block was placed back in a separate pouch and numbered. The bracket that was distorted during debonding was discarded and new samples were prepared (altogether 5 new samples were prepared. These 80 teeth were then recycled using the method in their respective group.

Sandblasting Group (Group II)

The sandblasting recycling (MicroEtcher CD, Danville Materials, California, USAmethod consisted of subjecting the bracket bases to aluminum oxide particles of size 50 μm after they were debonded using debonding pliers. The distance between the sandblasting handpiece and the bracket base was approximately 5 mm [Figure 3]. Each bracket was sandblasted within the range of 20-40 seconds under a pressure of 5 bars until the bonding resin was no longer visible to the naked eye and the bracket base appeared frosted. After sandblasting, the brackets were cleaned with acetone and dried with compressed air.

Figure 1: Sample used in the study

Figure 2: Lloyd universal testing machine

Thermal and Electropolishing Group (Group III)

Group III samples were recycled by thermal method, using a micro torch (Jaypee, Kozhikode, India) to burn off the old bonding material [Figure 4], then removing the remaining inorganic filler by scraping the bracket base with a probe – preliminary polishing and electropolishing the attachment – final polishing [Figure 5] (Jaypee, Kozhikode, India).

Adhesive Grinding Using a Tungsten Carbide Bur (Group IV)

Grinding of the bracket base was done using a tungsten carbide bur (DENTSPLY Limited, Surrey, UK) operated with a straight slow-speed handpiece (KAVO Electrotechisches Werk Gmbh, Leutkirch, Germany) at a speed of 25,000 revolutions/min for approximately 25 s until the composite was removed [Figure 6].[3] Care was taken during grinding not to expose and damage the metal mesh.[30]

Adhesive Removal with Er: YAG Laser (Group V)

Teeth belonging to group V were recycled by removing adhesive from the bracket using Er: YAG laser (Fidilis + 3, Fotona, Ljubljana, Slovenia, EU) [Figure 7]. Laser of 250 mJ energy at 12 Hz with an average power of 3 W was applied to the bracket for 5 s. The Er: YAG laser has a wavelength of 2940 nm. The adhesive was removed by holding the bracket with a bracket-holding tweezer away from the body and lasing the base of the bracket from top to bottom [Figure 8]. Protective eyewear provided by the manufacturer was used for the whole procedure.

Assessment of the Adhesive Remnant of the Bracket Surfaces by Environmental Scanning Electron Microscope

ESEM is an innovation in scanning microscopes specifically designed to study wet, oil-bearing, or insulating materials. The major advantage of ESEM over normal scanning electron microscopes is that it is not necessary to make non-conductive samples conductive, and thus, their original characteristics can be preserved for further testing or manipulation. Thus, non-conductive samples such as rocks or biological tissue samples can be looked at without the need for adding a

Figure 3: Sandblasting done

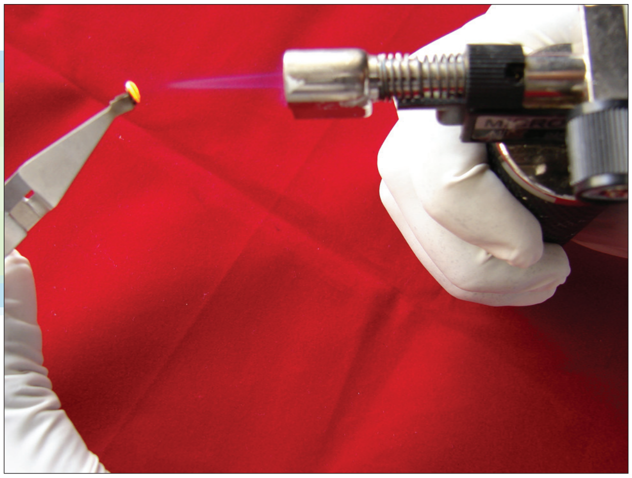

Figure 4: Burning old bonding material

Figure 5: Electropolishing

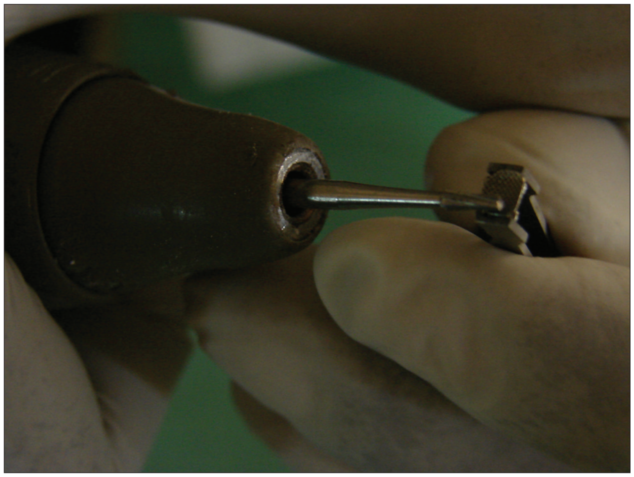

Figure 6: Adhesive grinding using tungsten carbide bur

conductive coating and the electron signal produces more than one ion per electron, so the signal is amplified without extra electronics that can add noise to the image.

After refurbishing, the brackets were investigated by the Environmental Scanning Electron Microscope (ESEM) (Philips Electrinics, XL 30 series, Amsterdam, the Netherlands) [Figure 9] at the Technical University of Vienna, Austria to find the effectiveness of the refurbishing methods. ESEM was done subjectively by investigating the bracket bases,

Rebonding of Teeth and Assessment of SBS

The 80 brackets belonging to the groups II, III, IV, and V were rebonded to the same re-prepared tooth to which they were bonded earlier in the similar fashion. The teeth were prepared by removing the residual composite resin using a tungsten carbide bur (DENTSPLY Limited, Surrey, UK) operated with a straight slow-speed handpiece[14] (KAVO Electrotech Nisches Werk Gmbh, K9, Germany) [Figure 10]. They were then immersed again for 24 h in artificial saliva prior to testing. Lloyd universal testing machine (model LR 100, AMETEK Measurement and Calibration Technologies, West Sussex, UK) [Figure 2] was used for SBS testing at a cross-sectional speed of 1 mm/min.[14] The load at the bracket failure was recorded by a computer connected to the Lloyd machine. The SBS values were calculated in megapascals (MPa).

Statistical Analysis

The differences between the Shear bond strength data were evaluated by one – way analysis of variance (ANOVA) and *post hoc* Duncan test using Tukey HSD method. The significance was determined at a probability value of P<0.05 for both the tests.

The statistical software Statistical Package for Social Science (SPSS) for windows (version 15) was used for the analysis of the data and microsoft word and excel was used to generate tables.

RESULTS

Assessment of SBS

A comparison between the SBS values after the teeth were recycled by four different methods and that of the control group is shown in Table 1. Using analysis of variance (ANOVA), there

Figure 7: Er: YAG laser used

Figure 8: Recycling with laser

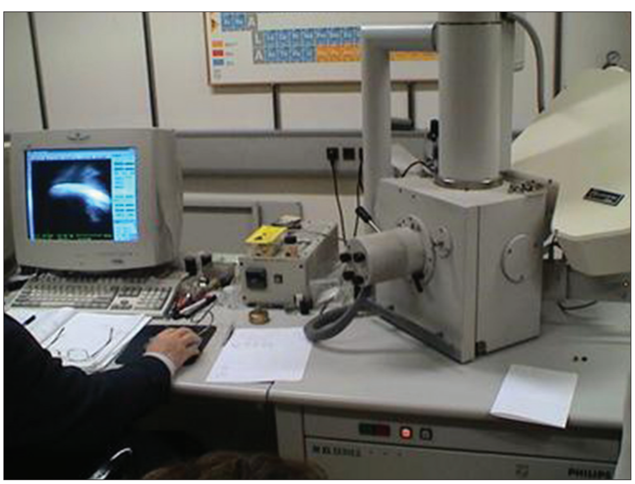

Figure 9: Philips XL 30 ESEM

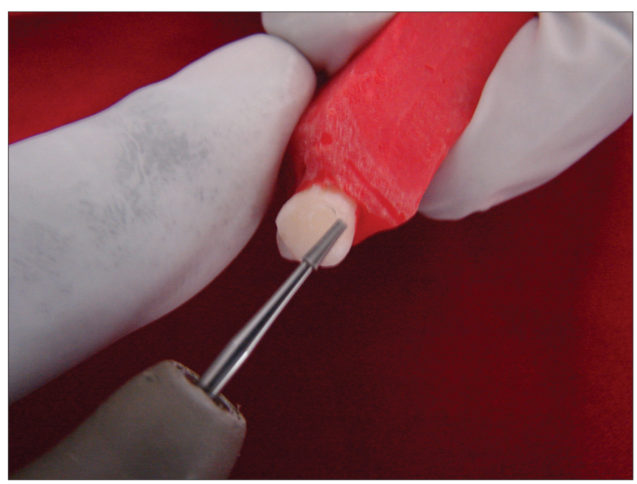

Figure 10: Removing adhesive from tooth

was statistical significance among the groups at *P*<0.001. The results indicated that the maximum recycled SBS value was seen in the laser method (group V) at 8.33±2.51 MPa, followed by the sandblasting (group II) at 6.12±1.12 MPa, thermal and electropolishing (group III) at 4.44±0.95 MPa, and lastly the adhesive grinding method (group IV) at 3.08±1.07 MPa.

In Table 2, it is seen that *post-hoc* tests and multiple comparison using the Tukey's honestly significant difference (HSD) method showed statistical significance between control (group I) and sandblasting, thermal, and tungsten carbide groups at *P*<0.001, but no significance between control and laser groups at *P*>0.05.

The mean SBS value of the sandblasting group (group II) was significantly different compared with the control group, tungsten carbide bur, and laser groups (*P*<0.001), but this was not significant compared with the thermal group.

Table 1: Comparison of mean shear bond strength of groups

Groups	*n*	Mean standard deviation	95% Confidence interval	Significance
Control	20	35.76	(2.86,17.22)	0.000*
Sandblasting	20	18.30	(3.88,8.36)	
Thermal and electropolishing	20	21.40	(2.54,6.34)	
Tungsten carbide bur	20	34.74	(0.94,5.22)	
Er:YAG laser	20	30.13	(3.31,13.35)	
Total	100			

*Shows the values are significant; Er:YAG – Erbium:Yttrium aluminum garnet

Thermal and electropolishing group (group III) showed significantly different mean SBS value compared with control and laser groups (*P*<0.001), but not with sandblasting group and tungsten carbide group.

Tungsten carbide bur group (group IV) demonstrated significant difference with control, sandblasting, and laser groups at *P*<0.001, but this was not significant compared with thermal group.

Lastly, the mean SBS value of the laser group (group V) showed statistically significant difference with sandblasting, thermal, and tungsten carbide groups (*P*<0.001), but no significance difference was seen with the control group.

Assessment of Adhesive Remnants on the Bracket Sufaces Using the ESEM

Sandblasting group (group II) [Figure 11]

Complete removal of the adhesive from the bracket base was not seen. The mesh and the inter-mesh cavities were filled with the adhesive even though no visible adhesive was remaining on the bracket, with the remnant adhesive found in curvatures, and only the overhanging adhesive was seen to be removed.

Thermal and electropolishing group (group III) [Figure 12]

Complete removal of the adhesive from the bracket base was not seen. Adhesive remnant was found remaining within the meshwork. The meshwork was also seen to be roughened.

Tungsten carbide bur group (group IV) [Figure 13]

Incomplete removal of the adhesive was seen in this group.

Table 2: Multiple comparisons

Group (I)	Group (J)	Mean difference (I-J)	Significance	95% confidence interval
Control	Sand blasting	3.91445*	0.000	3.7291
	Thermal and electro polishing	5.59730*	0.000	3.7292
	Tungsten carbide bur	6.95355*	0.000	3.7291
	Laser	1.70290	0.090	3.7292
Sand blasting	Sand blasting	−3.91445*	0.000	3.7291
	Thermal and electro polishing	1.68285	0.097	3.7291
	Tungsten carbide bur	3.03910*	0.000	3.7292
	Laser	−2.21155*	0.012	3.7291
Thermal and electro polishing	Sand blasting	−5.59730*	0.000	3.7292
	Thermal and electro polishing	−1.68285	0.097	3.7291
	Tungsten carbide bur	1.35625	0.263	3.7291
	Laser	−3.89440*	0.000	3.7292
Tungsten carbide bur	Sand blasting	−6.95355*	0.000	3.7291
	Thermal and electro polishing	−3.03910*	0.000	3.7292
	Tungsten carbide bur	−1.35625	0.263	3.7291
	Laser	−5.25065*	0.000	3.7291
Laser	Sand blasting	−1.70290	0.090	3.7292
	Thermal and electro polishing	2.21155*	0.012	3.7291
	Tungsten carbide bur	3.89440*	0.000	3.7292
	Laser	5.25065*	0.000	3.7291

*The mean difference is significant at the 0.05 level; Dependant variable: MPa; Tukey HSD

The mesh network and the adhesive were found scrapped to the same level and the adhesive was removed to that level only. Flattening and loss of meshwork was seen.

Er:YAG laser group (group V) [Figure 14]

Adhesive removal was found to be almost complete with this group. The bracket base was seen to closely resemble that of the control group [Figure 15]. The adhesive remnant on the bracket base was negligible. The meshwork was clearly visible, but a slight pickling of the metal was seen.

DISCUSSION

Matasa[31] has claimed that a bracket can be reused up to five times, whereas Wheeler and Ackerman's[32] observation was that single recycling was of negligible clinical importance. The Er:YAG Laser operates at a wavelength of 2940 nm and in a pulsed waveform. The FDA has cleared it for use on cementum and bone, and it has various hard-tissue applications, including caries removal, cavity preparation in both enamel and dentin, and preparation of root canals.[15-18]

The Er:YAG laser has several advantages. It produces clean and sharp margins in enamel and dentin. In addition, it can be used with a water spray, so pulpal safety is not a significant concern. The laser is antimicrobial when used within root canals and on root surfaces, and it removes endotoxins from the root surfaces.[18]

Finally, vibration from the Er:YAG laser is less severe than that from the conventional high-speed drill, and it is less likely to provoke discomfort or pain.[18] lasers have shown potential for removing calculus during root debridement, and compares favorably with traditional root planing. This laser is capable of multiple applications because its interaction with tissue is strongly influenced by variations in the air-to-water ratio of the spray.[16,17] It can be used on soft tissue, enamel, dentin, and bone, and its low interaction minimizes the risk of collateral damage. The ability to be used for multiple applications improves the economic feasibility of this laser.[18]

Er:YAG laser was used for the study because of the advantage of water spray and the depth of energy penetration is negligible. It is evident that the Er:YAG laser technique has the highest recycled SBS and is significantly greater when compared to the other methods. The increased shear bond values could be due to the lower penetration energy of Er:YAG laser and the selective absorption of the laser toward composites. An increase in penetration would have caused surface alteration of the metal, thereby reducing the bond strength. Selective absorption property of Er: YAG laser toward composites led to

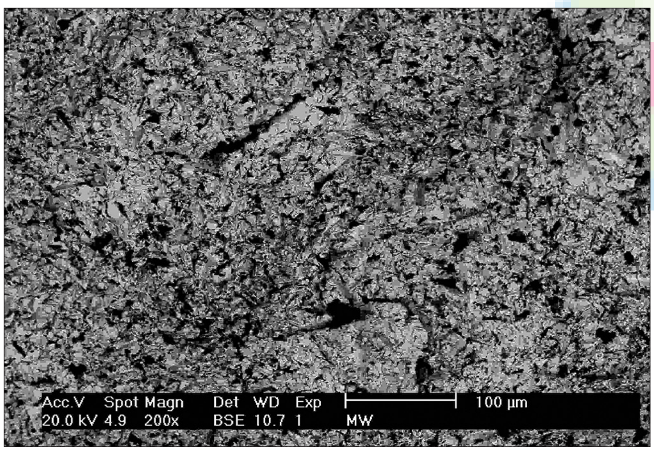

Figure 11: ESEM picture of bracket recycled by sandblasting method

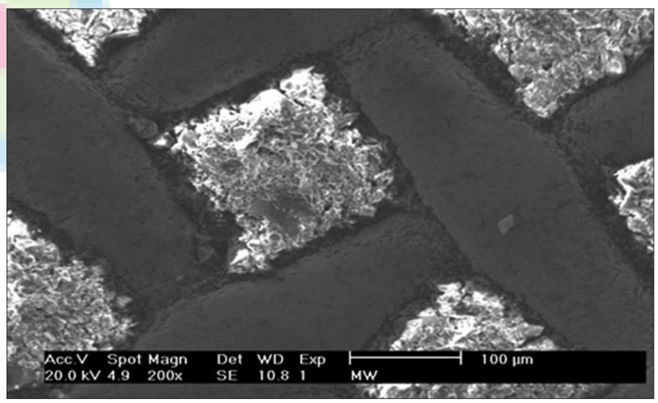

Figure 12: ESEM picture of bracket recycled by thermal and electropolishing method

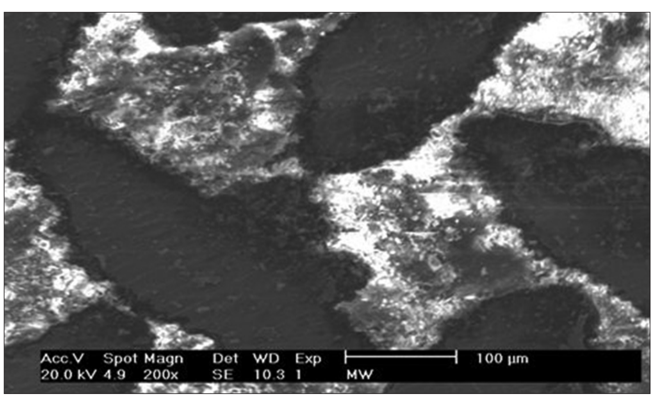

Figure 13: ESEM picture of bracket recycled by tungsten carbide method

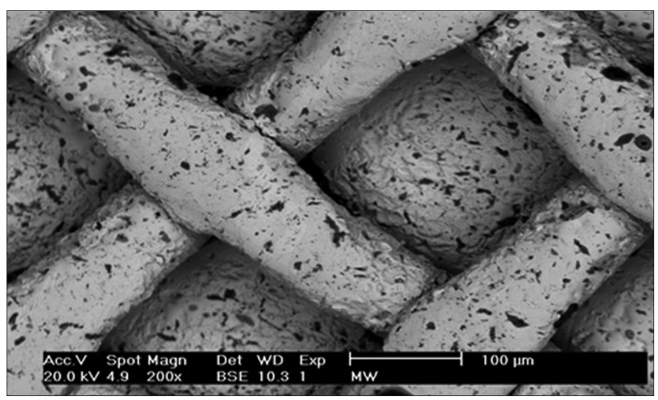

Figure 14: ESEM picture of bracket recycled by Er: YAG laser

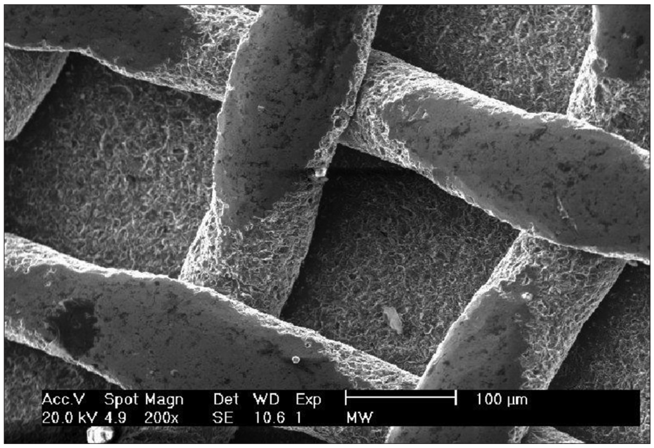

Figure 15: ESEM picture of the control group

the complete removal of resins from the brackets, which was directly proportional to the bond strength achieved[18]

The sandblasting method has the second highest recycled SBS. The increase in SBS values can be attributed to the micro-roughness created by the alumina particles, which therefore creates an increased bonding surface area that is essential for retention.

The mean recycled values of the thermal and electropolishing method were much below the normal range and require long exposure to heat. Complete pyrolysis of the resin occurs only at temperatures around 770°C, and during this phase of pyrolysis of resins, it forms acids which are a possible source of inter-granular attack.[4] According to Buchman,[4] heat influences stainless steel at temperatures of 400-900°C, which would definitely lead to sensitization of the metal.

In this study, only a flash electropolishing was done, which does not remove more than 5-10 μ of the metal. This, according to Wheeler and Ackerman,[32] does not significantly affect the bond strength. Exposure of a bracket to increased temperature also directly affects the hardness and theoretical tensile strength of the metal, which may render it more vulnerable to masticatory damage.[5] Brackets recycled by the thermal method render them more susceptible to tarnish and corrosion and this in turn can be responsible for its failure in the mouth.[33]

Exposure to heat may lead to stress relieving or softening of cold-worked metal, along with decreasing corrosion resistance. At the same time, this may produce a layer of metal oxide, which is removed by electropolishing, leading to a possible slot widening in the bracket and a reduction in mesh strand diameter loss of the metal.[2]

The adhesive grinding method using tungsten carbide bur recorded the least SBS well below the accepted limit and not fit for clinical usage. The grinding of the base using a tungsten carbide bur appears quick, simple, and easy to perform, but the grinding leaves behind a smooth surface with much of the mesh being scraped off.[3] This in turn leads to low bond strength values.

This study showed that the resulting bond strength after recycling with Er:YAG laser was the least affected and was above the recommended range.[34,35] However, a limitation of the study is that the assessment of adhesive remnants was done subjectively and future studies can use the Adhesive Remnant Indices (ARI) to more accurately assess the effectiveness of different recycling methods on the amount of adhesive remnants on bracket surfaces.[36-38]

CONCLUSIONS

The following conclusions were drawn from the study:

- Er:YAG laser was the most efficient method for recycling. The increased shear bond values could be due to the lower penetration energy of the laser and the selective absorption toward composites. ESEM evaluation showed adhesive removal to be almost complete with this group and the bracket base was seen to closely resemble that of the control group.
- Sandblasting method is the second most effective method of recycling, owing to the increased surface area, which creates better bonding.
- The adhesive grinding method is not a suitable method of recycling as the SBS value was much below the prescribed value for clinical usage due to incomplete removal of the adhesive and flattening and loss of meshwork as seen in ESEM.
- The mean bond strength following the thermal method was low, and its use also demands justification from the disadvantages it carries as shown by the various authors in their respective studies.

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