Analysis of the effects of some surface preparation methods on the bond strength of orthodontic attachments to amalgam surface

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ABSTRACT

This in-vitro research was aimed to examine the shear bond strength of metal brackets to silver amalgam using various surface preparation techniques to determine the best method to achieve appropriate bond strength between bracket and amalgam surface. Ninety amalgam blocks were divided into six groups and randomly assigned to one of the following conditioning groups (n=15): group 1 (control): etching with 37% phosphoric acid for 20 seconds, group 2: sand blasting with aluminum oxide (Al2O3), group 3: CO2 laser, group 4: CO2 laser plus sand blast, group 5: Er:YAG laser and group 6:Er:YAG laser plus sandblast. All Bond II was used in all groups and brackets were bonded with Transbond XT. After thermocycling, all samples were tested for shear bond strength by a universal testing machine. Data were analyzed by SPSS-22 software using Kruskal-Wallis and Mann-Whitney tests. The significance level was set at p≤0.05. The results showed the mean shear bond strength was significantly higher in all five experimental groups than in control group (p≤0.05). Shear bond strength was significantly higher in CO2 + sandblasting group than in sandblast group, but it was not significantly higher than Er:YAG, Er:YAG + sandblast and CO2 groups. Moreover, the results indicated a significantly higher shear bond strength in Er:YAG group than in sandblast group (p≤0.05). Preparation by CO2 + sandblast (with mean shear bond strength of 6.3 Mpa) showed a higher shear bond strength than other methods, so it is considered an acceptable preparation method.

Keywords: Surface treatment, amalgam, CO2 laser, Er:YAG laser, shear bond strength.

1. INTRODUCTION

The amalgam restorations are commonly found in posterior teeth, especially in young adults. Traditionally, orthodontic bands have been used in teeth with large amalgam restorations. However, bonded brackets have many advantages such as aesthetic improvement, elimination of band setting stage and separation of tooth, removal of band thickness and reduction of dental decalcification risk (Zachrisson, 1977; Mannerberg, 1960; Schaneveldt & Foley, 2002). The increasing number of adult patients seeking orthodontic treatment has encouraged investigations to improve the orthodontic bonding to silver amalgam. The techniques that have been introduced for bonding to amalgam surfaces include: 1. changing the metal surface (sandblast, creating surface roughness by diamond bur), 2. Using intermediate resins to improve the bond strength and 3. Using metal bond adhesives (Zachrisson et al., 1995; Germec et al., 2008).

Sandblasting with aluminum oxide is a method recommended for the preparation of amalgam surface to bond orthodontic attachments. It has been shown that alumina particles used in sandblasting create grooves on the surface, there by promoting the bond strength by increasing the contact surface (Germec et al., 2008; Sperber et al., 1999; Skilton et al., 2006; Jost-Brinkmann et al., 1996). In recent years, use of laser in dentistry has been taken into consideration. Since the introduction of Ruby laser by Maiman, several types of laser such as CO2, diode and Nd:YAG have been used in dentistry (Maiman, 2002). Erbium-doped yttrium aluminum garnet laser (Er:YAG) with a wavelength of 2940nm has been effectively used for dental hard tissue ablation, caries removal and cavity preparation. It has been shown that Er:YAG laser can create a bond strength on the enamel surface the same as conventional acid etching (Alavi et al., 2014).

CO2 laser is another hard tissue laser used for medical purposes, including dentistry. Its beam wavelength is 10600 nm with a gas active component. Akova et al. showed that CO2 laser (super pulse mode, 15 msec pulse duration, 2Hz frequency and 2,3,5,10,15 Watt output power) provided adequate bracket bonding to feldspathic porcelain and use of silane increased the bond strength (Akova et al., 2005). Although different methods have been recommended to improve bonding to amalgam surfaces, successful bonding of orthodontic brackets to bulk amalgam restorations is still a challenge for orthodontists. This study was aimed to compare the shear bond strength (SBS) of stainless steel brackets to silver amalgam using five different surface conditioning methods (37% phosphoric acid, sandblast with 50-µ Al2O3 abrasive particles, irradiation with CO2 laser, CO2 laser + sandblast, Er:YAG and Er:YAG + sandblast).

2. MATERIALS AND METHODS

The study sample included 90 8×8 mm amalgam blocks with 3 mm thickness, made of condensed silver amalgam (Kerr, Germany). To make the amalgam blocks, cavities with the mentioned dimensions were machined by laser on steel ingot. Based on the manufacturer’s instructions, the dental amalgam capsules were blended at high speed for 8s. using a faced-round condenser; they were then compressed into the cavities. After 24 hours, they were polished by rubber caps and amalgam molts. Maxillary central
incisor brackets (Orto Organizers Inc, Carlsbad, USA) with 11.03 mm² average base surface area were used. The prepared amalgam blocks were randomly divided into six groups, each group with one preparation method, as follows:

Group 1 (control): The surface of samples was etched by 37% phosphoric acid for 20 s and the samples were washed and dried by oil-free air/water spray.

Group 2: The amalgam surface was air abraded with 50-µm aluminum oxide particles by a microetcher (Pie Me S.R.L, Longigo-Veneza, Italy) at a 10-mm distance from the surface under 7-kg/cm² air pressure for 3 s.

Group 3: A CO₂ laser unit (Deka, Calezano, Italy) with 10600 nm wavelength, 1 W output power, 1 mm beam diameter, 10 Hz repetition rate (frequency), 5 ms pulse duration and 0.01 J/mm² energy density was used for surface preparation. The beam was applied at a 1-mm distance from the surface with an exposure time of 15 s.

Group 4: Preparation by CO₂ laser was carried out the same as group 3, followed by sandblasting with aluminum oxide particles according to the mentioned specifications.

Group 5: Er:YAG laser unit (Fotona, Fidelis plus, Ljubljana, Slovenia) with 2940 nm wavelength, 1 W output power, 600 µm beam diameter, 20 Hz frequency was used. The beam was applied at a 1-mm distance from the surface with exposure time of 5 s.

Group 6: Preparation by Er:YAG laser was carried out the same as group 5, followed by sandblasting with aluminum oxide particles according to the mentioned specifications.

For all samples, All-Bond II resin was applied according to the manufacturer’s instructions. One drop of primer A and one drop of primer B were mixed, and three layers of the mixture were applied to the amalgam surface by a microbrush. The brackets were then bonded to the surfaces separately with a light cure composite (Transbond XT, 3M-Unitek, USA) and cured for 20 s by a light cure device (Ortholux LED Curing light, 3M unitek, USA).

After bonding, the samples were thermocycled 1000 times at 5-55 °C (Behdad, Tehran, Iran). The samples were then kept in artificial saliva in an incubator (Incubator, Pars Azma Co) at 37 °C for 24 hours. After thermocycling, debonding was performed by a universal testing machine (K-21046, Walter+Bai AG, Lohningen, Switzerland). Each specimen was placed in the machine parallel to the force. A 250-kg tension cell was applied to the bracket-tooth interface with crosshead speed of 1 mm/min. The shear force was measured in newton (N) and reported as mega pascals (MPa) by the following equation: force (N)/surface (mm²) = (MPa). It should be noted that the samples were encoded before the bond strength test so that the operator was blind to them. Finally, data were analyzed by SPSS (Version 22) software using Kruskal-Wallis and Mann-Whitney tests. The significance level was set at p≤0.05.

### 3. RESULTS

The results showed the maximum shear bond strength (12.74 MPa) for the CO₂+sandblast group and minimum shear bond strength (1.88 MPa) for the control group (Table 1 and Figure 1). As shown in Table 1, Er:YAG+sandblast group had the highest shear bond strength after CO₂+sandblast group and the shear bond strength of CO₂ was similar to that of Er:YAG group.

Comparison of mean shear bond strength was also performed between different study groups. The normality of distribution of data was tested by one-sample Kolmogorov-Smirnov test, which showed data were not distributed normally. Therefore, non-parametric tests like Kruskal-Wallis and Mann-Whitney were used to compare the means. The results of Kruskal-Wallis test indicated a significant difference among the means of the six groups at 99.9% confidence interval (p=0.000). Considering these results, paired comparison of the study groups was done by Mann-Whitney test, whose results are presented in Table 2.

**Table 1** Descriptive statistics for shear bond strength of metal brackets to amalgam (MPa) by different surface preparation methods

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of samples</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>15</td>
<td>3.30</td>
<td>0.79</td>
<td>1.88</td>
<td>4.33</td>
</tr>
<tr>
<td>Sandblast</td>
<td>15</td>
<td>4.16</td>
<td>0.77</td>
<td>3.13</td>
<td>5.61</td>
</tr>
<tr>
<td>CO₂</td>
<td>15</td>
<td>5.14</td>
<td>1.32</td>
<td>4.17</td>
<td>7.59</td>
</tr>
<tr>
<td>CO₂+sandblast</td>
<td>15</td>
<td>6.37</td>
<td>3.09</td>
<td>2.99</td>
<td>12.74</td>
</tr>
<tr>
<td>Er:YAG</td>
<td>15</td>
<td>5.10</td>
<td>1.23</td>
<td>3.58</td>
<td>7.04</td>
</tr>
<tr>
<td>Er:YAG+sandblast</td>
<td>15</td>
<td>5.54</td>
<td>2.52</td>
<td>3.52</td>
<td>11.68</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 1 Bar Chart of the shear bond strength (SBS) of metal brackets to amalgam (MPa) by different surface preparation methods.

Table 2 Matrix of Mann-Whitney test results for comparison of mean shear bond strength of metal brackets to amalgam

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Sandblast</th>
<th>CO₂</th>
<th>CO₂ + sandblast</th>
<th>Er-YAG</th>
<th>Er-YAG + sandblast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>-</td>
<td>0.004</td>
<td>0.000</td>
<td>0.001</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Sandblast</td>
<td>-</td>
<td>-</td>
<td>0.67</td>
<td>0.020</td>
<td>0.0030</td>
<td>0.082</td>
</tr>
<tr>
<td>Co₂</td>
<td></td>
<td>-</td>
<td>-</td>
<td>0.519</td>
<td>0.782</td>
<td>0.868</td>
</tr>
<tr>
<td>Co₂ + sandblast</td>
<td></td>
<td></td>
<td>-</td>
<td>0.269</td>
<td>0.318</td>
<td></td>
</tr>
<tr>
<td>Er-YAG</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>0.868</td>
<td></td>
</tr>
<tr>
<td>Er-YAG + sandblast</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The results of Mann-Whitney test showed significantly higher mean shear bond strength in CO₂ + sandblast group than in sandblast group (p≤0.05). Further, the mean shear bond strength was significantly higher in the CO₂ + sandblast group than in the control group (p≤0.05). The mean shear bond strength was significantly higher in Er:YAG group than in sandblast group (p≤0.05) and the mean shear bond strength was significantly higher than in the sandblast group than in the control group (p≤0.05). Furthermore, the mean shear bond strength was significantly higher in the Er:YAG + sandblast group than in the control group (p≤0.05). The mean shear bond strength was also significantly higher in the CO₂ group than in the control group (p≤0.05). As shown in Table 2, the results of Mann-Whitney showed no significant difference in the shear bond strength between other groups.

4. DISCUSSION
Although different surface preparation methods, including mechanical (roughening by diamond bur and sandblasting) (Zachrisson et al., 1995; Sperber et al., 1999; Skilton et al., 2006; Harari, 2000) and chemical treatments (Ga-Sn liquid application and chemical corrosion) (Sperber et al., 1999; Gross et al., 1997), have been suggested for effective bonding to non-enamel surfaces, satisfactory orthodontic bonding of stainless steel brackets to posterior amalgam restorations is an important clinical problem (Germec et al., 2008). The present study evaluated the effect of five surface treatment methods (37% phosphoric acid, sandblast with 50-μ Al₂O₃ abrasive particles, irradiating with CO₂ laser, CO₂ laser + sandblast, Er:YAG and Er:YAG + sandblast) on the shear bond strength of
orthodontic stainless steel brackets to amalgam surfaces. Sandblast is one of the common surface preparation methods used to enhance the shear bond strength. It has been demonstrated that air abrasion with Al₂O₃ particles increases the bonding surface area by creating scratch-like irregularities (Sperber et al., 1999; Oskoee et al., 2012; Atta et al., 1990). Hardness differences among various amalgam phases result in the selective erosion of soft phases (Sperber et al., 1999).

The results of the present study showed that sandblasting provided significantly higher bond strength than the control group, which is consistent with the results of Sperber et al. and Skilton et al. (Sperber et al., 1999; Skilton et al., 2006). CO₂ and Er:YAG lasers showed positive effects in this study and CO₂+sandblast had a significantly higher effect than other preparation methods. Er:YAG laser has been used in a series of dental procedures, including caries removal. This laser creates sharp edges during cavity preparation and its pulpal damage is very limited due to low penetration depth at 2040 nm wavelength (David & Gupta, 2015). Hibstand Keller reported that Er:YAG laser could ablate the amalgam surface and produce micro craters (Hibst & Keller, 1991). Hosseini et al. evaluated the amalgam surfaces treated by different output powers of Er:YAG laser using Scanning Electron Microscope (SEM) and showed some pitting areas with non-homogenous irregularities. The authors concluded that sandblast+Er:YAG laser could produce a proper surface for the bonding of orthodontic attachments (Hosseini et al., 2015). Our results also showed use of sandblast plus lasers increased the shear bond strength.

CO₂ with a wavelength of 10600 nm is another type of laser used in medicine. Second to Er:YAG laser, it is absorbed well in water, so it is used for cutting, coagulating, controlling soft tissue bleeding and treating mucosal lesions and gingival diseases. CO₂ laser was the first laser introduced by Patel in 1964 to be used for both soft and hard tissues (David & Gupta, 2015). In line with the present study, Naseh et al. reported amalgam surface preparation by Er, Cr:YSGG laser showed the highest bond strength (Naseh et al., 2016). Alizadeh Oskoee et al. reported the highest bond strength for the Er, Cr:YSGG laser and the lowest bond strength for the control group. Moreover, a significant difference was observed between the laser group and control and sandblast groups in terms of shear bond strength (p<0.05), but no significant difference was found between sandblast and control groups (p=0.5), which contradicts the results of the present study (Oskoee et al., 2012).

Goymen et al. examined the impact of laser, sandblast and acid etching preparation techniques on the shear bond strength of orthodontic brackets to temporary crown materials. They reported a higher shear bond strength in Er:YAG laser than in the other two groups. They argued adhesives are able to penetrate into the laser-induced porosities, which consequently elevates the bond strength (Goymen et al., 2015). In the present study, the shear bond strength was significantly higher in Er:YAG laser than in sandblast and control groups, confirming the results of Goymen et al. Higher bond strength in the laser-irradiated group may be mainly due to the presence of micro-irregularities and oxide layer preservation (Oskoee et al., 2012). In contrast with our results, some studies have reported no rise in bond strength using lasers in non-enamel surfaces (Gundogdu et al., 2014; Shiu et al., 2007). Although CO₂ laser has been utilized for the treatment of other surfaces such as porcelain (Ahrari et al., 2017), to the best of the researcher’s knowledge, this laser has not been applied to amalgam surfaces. Several studies have recommended a minimum shear bond strength of 5 MPa for a successful clinical bond in orthodontics (Elekdag-Turk et al., 2007), while some others have suggested the shear bond strength of 6.5-10 MPa as a desirable level (Lopez, 1980). Reynolds et al. showed the shear bond strength of 5.9-7.8 MPa for the proper clinical bonding of orthodontic brackets (Reynolds, 1975). Thus, the laser groups in the present research showed a sufficient orthodontic bonding to amalgam. In addition to mechanical retention, chemical bonding to amalgam surfaces is another advantage of metal bond adhesives and intermediate resins. All-Bond II is an intermediate resin with a proper bonding ability to amalgam (Zachrisson et al., 1995). Although it has a lower bond strength to amalgam surfaces than 4-META resins, it has been reported to have low clinical failure rates in bonding to sandblasted amalgam surfaces (Büyükılımaz & Zachrisson, 1998; Zachrisson, 2000).

In spite of the favorable results found in the laser groups, dental staff should consider the release of mercury vapor during laser application as a potentially detrimental element due to the small amount of un-reacted mercury in the amalgam structure (Cernavin & Hogan, 1999). The results of this study revealed that sandblast+CO₂ laser had the highest shear bond strength among the preparation methods and had a higher effect on the shear bond strength than sandblast alone. CO₂ laser alone was also more efficacious than sandblast. Thus, CO₂ laser+sandblast can be a good candidate for the preparation of amalgam surfaces in orthodontic attachments. Generally, sandblast and laser have a significant effect on the preparation of amalgam surfaces and their simultaneous application enhances the amalgam surface preparation process and shear bond strength.

5. CONCLUSION
The results of this study showed the mean shear bond strength of CO₂+sandblast (6.37 MPa) with application of All Bond II was in an acceptable range, so it can be used a proper method for amalgam surface preparation. Further, Er:YAG laser has a higher efficacy than sandblast in increasing the bond strength. In general, Er:YAG and CO₂ lasers have a positive effect on amalgam surface
preparation. Further studies are required to evaluate the effect of lasers with powers different than what were used in the present study. Higher bond strength may be achieved by changing the physical properties of lasers.

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**Conflict of Interest**

The authors declare that they have no conflict of interest.

**Ethical code**

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