Debonding of ceramic brackets by a new scanning laser method

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Introduction: The purpose of this in-vitro study was to develop a new method to debond ceramic brackets by scanning with an Er:YAG laser. Methods: Sixty bovine mandibular incisors were randomly divided into 2 groups of 30. Polycrystalline ceramic brackets were placed on their labial surfaces by using the orthodontic composite adhesive Transbond XT (3M Unitek, Monrovia, Calif) and light cured for a total of 40 seconds. The first group was the control group, with no laser application performed. The Er:YAG laser was used on each bracket in the study group at 4.2 W for 9 seconds with the scanning method. The force required for debonding the brackets was applied 45 seconds after laser exposure. Shear bond strengths were measured in megapascals with a universal testing machine, and adhesive remnant index scores were assigned to each specimen. Results: Statistically significant (P <0.001) lower shear bond strengths were found in the laser group (9.52 MPa) compared with the control group (20.75 MPa). Likewise, the adhesive remnant index scores were statistically different (P <0.001); the laser group had twice as many samples with adhesive, with the adhesive remnant index scores of 2 or 3. Conclusions: The application of the Er:YAG laser with the scanning method is effective for debonding ceramic brackets by degrading the adhesive through thermal softening. (Am J Orthod Dentofacial Orthop 2010;138:195-200)
heated until it softens. As the result of thermal softening, the bracket slides off the tooth surface. If the heating is fast enough to raise the temperature of the resin into its vaporization range before thermal softening occurs, thermal ablation takes place. The bracket blows off the tooth surface as the result of thermal ablation. The bracket also blows off the tooth from photoablation, which occurs when the energy level of the bonds between the bonding-resin atoms rapidly rises above their dissociation energy levels, resulting in the decomposition of the material.

Debonding with thermal softening occurs at low power densities, whereas thermal ablation and photoablation happen at high power densities. All monocrystraline brackets were debonded in less than 1 second by either thermal ablation or photoablation. The brackets still felt cool after debonding, since thermal ablation and photoablation proceeded rapidly with little heat diffusion that caused the tooth and the bracket to stay near physiologic temperatures. On the other hand, polycrystalline brackets were too hot to touch because they were debonded by sliding down under the influence of the applied force as a result of thermal softening. However, in their study, no intrapulpal temperature change was measured.2

Mimura et al14 used a carbon dioxide laser to investigate the differences in the laser-aided debonding mechanism between 2 adhesives. They evaluated these adhesives according to debonding force, debonding time, total illuminated laser energy, and modified adhesive remnant index. Unlike previous studies, they applied the force and the lasing simultaneously. They concluded that the laser-focused adhesives tended to be removed with the brackets in the Bis-GMA groups, whereas the adhesives tended to remain on the tooth surface in the MMA groups.

Ma et al16 and Rickabaugh et al17 used carbon dioxide lasers and modified debonding pliers to accurately position the laser beam on the ceramic bracket. In accordance with previous studies, their results showed significant differences in tensile debonding forces between the control and study groups. They also stated that the bracket could be removed from the tooth with pliers as soon as the adhesive-softening temperature had been reached, and the debonding pliers holding the bracket reduced the possibility of dropping it on the patient. Additionally, quick removal of the bracket prevented the heat energy stored in the bracket from transmitting to the tooth.

Obata et al15 investigated bonding and debonding of ceramic brackets in vitro and in vivo with super-pulse and normal-pulse carbon dioxide lasers. An in-vivo study was performed for the removal of brackets by 1 operator in which a rotational force was applied with tweezers to disengage the bracket after lasing each tooth. The shear force was then measured in vitro by using 2 and 3 W generated by the super-pulse laser. They concluded that super-pulse carbon dioxide laser debonding is clinically more useful than laser etching for orthodontic treatment.

Hayakawa18 stated that ceramic brackets were debonded effectively using a high-peak power Nd:YAG laser at 2.0 J or more. The laser energy was applied to the mesiodistal centers of the gingival surface and the coronal surface under each bracket wing, which is labio-lingually the thinnest part of the ceramic bracket. The shear test was performed after the laser pulse had been applied; however, the time interval between the shear test and the lasing was not mentioned.

All of these previous studies confirm the efficiency of laser debonding of ceramic brackets. On the other hand, possible side effects of these different laser types, application techniques, and variables on tooth structures should be kept in mind. Therefore, to prevent undesirable results, an appropriate method that could be easily used in the clinic practice should be developed.

The purpose of this in-vitro study was to develop a new method to debond ceramic brackets by scanning with an Er:YAG laser.

MATERIAL AND METHODS

Sixty freshly extracted, noncarious bovine permanent mandibular incisors were used in this study because of their similar properties to human enamel.22,23 The roots were cut away, and soft-tissue debris and coronal pulps were removed. The prepared samples were stored in 0.1% thymol solution until use.

The bonding surfaces of the enamel were polished with a nonfluoridated pumice paste for 15 seconds, rinsed, and dried with compressed air. The teeth were then conditioned with 37% phosphoric acid for 30 seconds, followed by thorough washing and drying. Sixty polycrystalline alumina brackets (Transcend series 6000, 3M Unitek, Monrovia, Calif) were bonded by 1 operator (M.O.Ö.). Force was applied until the composite material overflowed from all margins of the brackets and the base of the brackets touched the labial surfaces of the incisors. Orthodontic composite adhesive Transbond XT (3M Unitek) was used and cured with a halogen light-curing unit (Optilux, Kerr, Orange, Calif) for 20 seconds on the mesial and distal sides, as recommended by the manufacturer. Each tooth was adjusted with a guiding device to reproducibly position the bracketed teeth during testing. The teeth were embedded in an autocatalyzing epoxy resin (Fortex Cold Curing Dental Polymer 2000; Willmann & Pein GmbH, Hamburg, Germany) with the labial surfaces and the brackets exposed. Before testing, all samples were stored in distilled water at 37°C for 48 hours.
The teeth were randomly assigned to 2 groups of 30 brackets to be debonded with and without lasing. The laser we selected was the Er-YAG (DEKA Smart 2940 D Plus, VersaWave, HoyaConbio, Fremont, Calif) at a power of 4.2 W with a wavelength of 2940 nm. The laser energy was applied by scanning thoroughly the surface of the brackets for 9 seconds. Scanning was done with horizontal movements parallel to the bracket slot starting from the upper distal wing of the bracket to the upper mesial wing, and then to the slot of the bracket and the lower wings (Figs 1 and 2). The application tip with a diameter of 1 mm was positioned perpendicularly 2 mm from the bracket.

The shear test was performed 45 seconds after the laser pulse had been applied. In clinical practice, for lasing the 5 teeth on the half arch before debonding, a total of 45 seconds is necessary when each tooth is lased for 9 seconds. To evaluate the bond strength of each specimen, the shear bond strength was measured with a universal testing machine (Instron, Canton, Mass) with a shear blade. The force was applied to the bracket occluso-gingivally, producing a shear force at the bracket-tooth interface. A computer electronically connected to the testing machine recorded the results of each test. Shear bond strengths were measured in megapascals at a crosshead speed of 1 mm per minute. The bracket bases and the enamel surfaces were examined under a light stereomicroscope at 20-times magnification, and the adhesive remnant index (ARI) scores were assigned to each specimen. A score of 0 indicated that no adhesive was left on the tooth in the bonding area, 1 indicated that less than half of the adhesive was left on the tooth, 2 indicated that more than half was left on the tooth, and 3 indicated that all adhesive was still on the tooth with a distinct impression of the bracket mesh on the remaining adhesive surface.

**Statistical analysis**

Statistical calculations were performed with Prisma software (version 3.0, GraphPad, San Diego, Calif) for Windows. In addition to standard descriptive statistical calculations (means and standard deviations), an unpaired t-test was used in the comparison of the groups, and a chi-square test was performed to evaluate the qualitative data. A Spearman correlation test was used for variables correlation. The statistical significance level was established at \( P < 0.05 \).

**RESULTS**

The results showed statistically significant differences between the control and study groups \( (P < 0.001) \). The shear test showed significantly lower shear bond strengths in the laser group. The data are summarized in **Tables I through III**. Chi-square analysis determined that the ARI scores were statistically different \( (P < 0.001; \text{Table III}) \).

The shear strength values were 20.75 MPa for the control group and 9.52 MPa for the study group. When the ARI scores were considered, 0 score was not found, and only 1 score of 1 was found for the laser group; 14 samples had scores of 0 and 1 in the control group. Also, the results for the laser group had almost twice as much adhesive, with ARI scores of 2 and 3.

A negative correlation was found between bond strengths and ARI scores \( (P < 0.001) \): as the shear bond strengths decreased, the ARI scores increased.
DISCUSSION

In clinical use, adequate force to debond a bracket was shown to be 6 to 8 MPa. The force should be kept in this range to prevent damage to the teeth and periodontal structures. On the other hand, debonding of ceramic brackets can reach values approaching 20 MPa, which can cause enamel cracks or tear outs. To prevent these complications and facilitate the process, laser-initiated debonding mechanisms were developed that work by degrading the adhesive resin. Our results are generally consistent with previous studies, verifying that lasers are effective for the removal of ceramic brackets by thermally softening the adhesive resin. As the Er:YAG laser degraded the resin, a negative correlation occurred between bond strengths and ARI scores that reduced the risk of enamel fracture. Also, the ARI scores were almost within the secure range, similar to previous studies.

According to Tocchio et al, debonding mechanisms that enable adhesive resin to degrade by laser energy can be explained by thermal softening, thermal ablation, or photoablation. During thermal softening, decomposition of the adhesive resin is obtained by heat transmitted thorough the bracket. Therefore, in most previous studies, carbon dioxide lasers whose wavelength is more easily absorbed by the ceramic brackets had been preferred for debonding. However, when obtaining sufficient heat, the rise of the bracket temperature can cause an increase in intrapulpal temperature that might cause pulp damage.

Because of the risk of pulp damage with thermal softening, a different laser type that would directly influence the resin by enhancing the effects of thermal ablation and photoablation was used by Hayakawa. A high-peak Nd:YAG laser was selected, since it has a lower ceramic absorption level than the carbon dioxide laser. The results showed that some polycrystalline and monocrystalline brackets were debonded by thermal ablation or photoablation immediately after irradiation. Thermal ablation and photoablation occur when high-energy laser light interacts with the adhesive material, causing it to decompose. Laser light transmission without loss of energy through the bracket to the resin is believed to be important for achieving this phenomenon. Depressions of decomposition of the bracket bases, black deposits, localized carbonization-like changes to the remnant resin, and eruptions of dissolved ceramic on the bracket bases were reported. These burned-out spots verified the higher degree of enamel transmissibility of the Nd:YAG laser than from the carbon dioxide laser. Because of the short application period, the rise in intrapulpal temperature was only measured as 5.1°C. Therefore, when using Nd:YAG lasers, care should be taken because of the amount of heat conducted and the length of its application.

Polycrystalline brackets do not have a uniform crystal structure that enables high transmissibility. This

Table II. Frequency distribution of shear bond strength of the groups

<table>
<thead>
<tr>
<th>Shear bond strength (MPa)</th>
<th>Laser group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of items</td>
<td>Frequency distribution</td>
<td>Number of items</td>
</tr>
<tr>
<td>1-2.99</td>
<td>1</td>
<td>3.3%</td>
</tr>
<tr>
<td>3-4.99</td>
<td>1</td>
<td>3.3%</td>
</tr>
<tr>
<td>5-6.99</td>
<td>3</td>
<td>10.0%</td>
</tr>
<tr>
<td>7-8.99</td>
<td>6</td>
<td>20.0%</td>
</tr>
<tr>
<td>9-10.99</td>
<td>12</td>
<td>40.0%</td>
</tr>
<tr>
<td>11-12.99</td>
<td>2</td>
<td>6.6%</td>
</tr>
<tr>
<td>13-14.99</td>
<td>5</td>
<td>16.6%</td>
</tr>
<tr>
<td>15-16.99</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>17-18.99</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>19-20.99</td>
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</tr>
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<td>21-22.99</td>
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<td>23-24.99</td>
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<td>25-26.99</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>27-28.99</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>29-30.99</td>
<td>-</td>
<td>0%</td>
</tr>
</tbody>
</table>

Table III. Frequency distribution of ARI scores

<table>
<thead>
<tr>
<th>ARI score</th>
<th>Control group</th>
<th>Laser group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of items</td>
<td>Frequency distribution</td>
<td>Number of items</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>10.0%</td>
</tr>
<tr>
<td>1</td>
<td>11</td>
<td>36.7%</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>40.0%</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>13.3%</td>
</tr>
</tbody>
</table>
increases the laser energy loss passing through the bracket to reach the resin, so, for debonding ceramic brackets, a laser should be chosen that will directly affect the resin without conducting too much heat.

Standardization of the thickness of the composite material is an important factor in studies concerning shear bond strengths. As in our study, in previous studies, there was no specific method for exact standardization of the composite material. But bonding central incisor brackets to bovine teeth with smooth surfaces would help to obtain results with minimal errors, as we did.

In our study, the Er:YAG laser was selected because, even though it has similar effects on adhesive resin, it appears to have lesser thermal effect than the Nd:YAG laser. Additionally, to reduce the heat conduction to the pulp, the effect of the energy was tried to be reduced by scanning through the surface of the bracket and not applying it on just 1 point. The probable rise at 1 point could be avoided, since the application tip was mobile and would not be held on any point. Meanwhile, time could be provided for the tissues to cool. But the duration of lasing is longer in scanning than the other techniques presented before. We are now studying the thermal effects of the technique, and the results will be presented soon. Infrared lasers such as Er:YAG, Nd:YAG, and carbon dioxide primarily have a thermal effect on water-containing tissues. The laser light of the Er:YAG laser can be absorbed by resin that might contain a readily vaporizable constituent, such as water or residual monomer. Therefore, the effect of scanning with the Er:YAG laser as in our study can result in decomposition of the resin because of evaporation of the water or the monomer. The reason that adhesive resin is not as strong as before when it cools might be due to this decomposition, in addition to softening while hot. Consequently, this takes away the need to apply force while lasing the bracket; this is not practical for daily clinical use. Additionally, this eliminates the risk of dropping the hot bracket in the oral cavity. Also, with this technique, debonding half of a dental arch requires no extra equipment to hold the brackets. Also, standard preventive processes such as bite wax to secure the periodontal structures would be enough, since the applied shearing forces are at the desired levels.

As a result, this method might be an effective clinical way to reduce the shear bond strengths of orthodontic ceramic brackets from high values to the desired levels. Further studies are necessary to investigate the thermal effects of this method on the pulp tissues.

CONCLUSIONS

Er:YAG laser irradiation on ceramic brackets with scanning method produced the following findings.

1. Laser-aided debonding with this scanning method was efficient for debonding ceramic brackets without enamel tear outs or bracket fractures.
2. Er:YAG laser use increased the ARI scores and thus decreased the risk of enamel fracture.
3. The Er:YAG laser is effective for reducing the shear bond strengths of orthodontic polycrystalline ceramic brackets from high values to levels for safe removal from the teeth.

REFERENCES