Orthodontic Bonding with Varying Curing Time and Light Power Using an Argon Laser

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ABSTRACT

Objective: To test the effects of curing time and light intensity on the shear bond strength of adhesive composites for stainless-steel orthodontic brackets.

Materials and Methods: An argon laser at four different power settings (100, 150, 200, and 250 mW) and four different exposure times (5, 10, 15, and 20 seconds) was used to bond adhesive-precoated (APC) stainless-steel incisor brackets to the facial surfaces of 154 bovine incisors. The shear bond strength of each specimen in 16 randomly divided groups was randomly tested to failure using an Instron universal testing machine. Each mode of failure was described using the adhesive remnant index (ARI).

Results: The ARI scoring system showed that the location of bond failure did not differ significantly in relation to exposure time (P = .40). However, the location of bond failure was significantly different in relation to light power (P = .03).

Conclusions: A short exposure time and a low power setting produce shear bond strengths equivalent to those produced by longer exposure times and higher power settings.

KEY WORDS: Orthodontic bonding; Argon laser

INTRODUCTION

Clinical efficiency is critical in a period when more patients are seeking orthodontic treatment. A streamlined bonding process is an important consideration, and the choice of light source is critical. Light curing sources include halogen, plasma arc, argon laser, and light-emitting diode units. Conventional curing lights (tungsten and halogen) are being replaced by much faster curing systems: plasma arc and argon laser. Laser curing systems offer rapid curing while maintaining and possibly improving the physical properties of the adhesives. Improved physical properties include hardness, tensile strength, transverse flexural strength, compressive strength, shear bond strength, and degree of polymerization. Although laser manufacturers provide guidelines on the light intensity and exposure duration when curing composite resins, there is little objective evidence to support their use.

Laser light is monochromatic, whereas conventional sources produce light that is polychromatic. The initiator within composite adhesives is camphorquinone, which is sensitive to light in the blue region of the visible spectrum with the peak of activity centered around 480 nm. The argon laser is an excellent light source because it produces a peak wavelength of 488 nm. Because conventional light sources are polychromatic, only a small portion of the light energy is absorbed by the camphorquinone, with the rest lost as heat.

Laser light is also coherent, which enables the beam to be collimated and thus focused onto a small spot. Conventional light sources are not coherent and thus produce disorganized radiant energy. Because of this noncoherence, an increase in the distance between the conventional light source and the composite decreases the power density of light reaching the composite and thus decreases the shear bond strength. In contrast, Hinoura et al found that the bond strengths of composites did not decrease when in-
creasing the distance between the laser to the composite from 0.0 mm to 1.5 mm.

Many experiments have been conducted testing the effects of lasers on adhesive properties.\textsuperscript{2-4,10,11} In contrast, few experiments have been conducted testing the effects of lasers on orthodontic bonding. The argon laser produces bond strengths that are equivalent to those produced by conventional light sources. Also, the argon laser produces these bonds in less time than conventional light sources.\textsuperscript{12-15} However, the literature reveals only three reports evaluating the effects of various curing times\textsuperscript{13,16} and light intensities\textsuperscript{14} on the bond strength of adhesives for orthodontic brackets.

Lalani et al\textsuperscript{13} compared the shear bond strength of adhesives for stainless-steel orthodontic brackets bonded with an argon laser at a power setting of 300 mW for different exposure durations. No statistically significant difference in the mean shear bond strength was shown when cured for 5, 10, or 15 seconds. However, a high degree of enamel fracture (16.2\%-21.6\%) was reported, indicating that in about 20\% of the specimens that the enamel strength was tested rather than the bond strength of the adhesive. Talbot et al\textsuperscript{14} used a 10-second exposure duration and three different power settings (200, 230, and 300 mW) but observed no significant difference in bond strength among the groups. Kurchak et al\textsuperscript{16} found that the tensile bond strength of adhesives for stainless-steel orthodontic brackets increased when the curing time of an argon laser was increased from 2 seconds to 10 seconds. However, the statistical significance of the results and the power setting of the laser were not reported.

To a limited degree, increased light intensity should be able to substitute for reduced exposure time and vice versa. However, because the simultaneous effect of time and intensity on curing orthodontic bracket bonds is not well understood, which combination will yield the greatest bond strengths is not known. Increasing the exposure time allows the light source to reach a greater amount of camphorquinone within the adhesive, provided that the light is able to penetrate adequately. However, it is possible to reach a point of diminishing returns, and thus if the light cannot penetrate the adhesive adequately, an increase in exposure time will have no effect on further polymerization of the adhesive.

The effect of light intensity is more complex than that of exposure duration. Low intensities do not provide enough energy to penetrate the adhesive and subsequently activate the camphorquinone. Conversely, excessively high intensities will convert a great amount of camphorquinone to its free radical state in a short time period, thus resulting in the formation of weak small-chain polymers rather than relatively stronger long-chain polymers. Therefore, the use of an intensity that is neither too low nor too high is imperative for proper polymerization and subsequent production of greater bond strengths.

An “ideal” orthodontic bond strength is not merely the greatest bond strength possible. The “ideal” bond strength should withstand orthodontic and masticatory forces, yet allow for easy bracket removal when desired. According to the published literature, 6 MPa to 8 MPa is a clinically sufficient bond strength for most circumstances.\textsuperscript{17} In addition, the force needed to remove the orthodontic bracket should be low enough to prevent enamel fracture.

The purpose of the present study was to test the effects of curing time and light power on the shear bond strength of adhesive composites for stainless-steel orthodontic brackets.

**MATERIALS AND METHODS**

The crowns of 160 bovine incisors without visible enamel defects were selected for bonding. The teeth were disinfected in 0.5\% Chloramine-T solution and stored in deionized water with thymol crystals for the remainder of the experiment. Each tooth was randomly assigned to one of 16 groups (combinations of 4 curing times and 4 curing intensities) and subsequently mounted into a small epoxy cylinder with the facial surface exposed and parallel to the base of the cylinder.

To produce a chalky enamel surface, the enamel surfaces were (1) lightly sanded with 600-grit sandpaper for 5 seconds to create a smooth flat surface of enamel, (2) polished for 10 seconds with a rubber prophyl cup and fluoride-free pumice and water, (3) rinsed for 10 seconds with deionized water from an air-water syringe, (4) dried for 5 seconds with air from an air-water syringe, (5) acid-etched for 20 seconds with 37\% phosphoric acid gel (3M Unitek, Monrovia, Calif), (6) rinsed for 10 seconds with deionized water from an air-water syringe, (7) dried for 5 seconds with air from an air-water syringe, and (8) coated with a thin layer of Transbond XT primer (3M Unitek, Monrovia, Calif).

Precoated stainless-steel twin incisor brackets (APC II Victory Series; 3M Unitek, Monrovia, Calif) were bonded to the prepared enamel specimens. Each bracket was placed on the bonding surface by hand and fully seated into position by using a standardized pressure from a modified articulator.\textsuperscript{18} The excess adhesive was removed, and the remainder was cured using the AccuCure 3000 argon laser (LaserMed, West Jordan, Utah) with an orthodontic light tip (1.2 mm in diameter). The laser was operated for the duration and at the intensity that corresponded to that particular group of teeth. Combinations of four curing times (5, 10, 15, and 20 seconds) and four power set-
TABLE 1. Number of Successfully Tested Specimens in Each Group

<table>
<thead>
<tr>
<th>Time, s</th>
<th>Power, mW</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>9</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>9</td>
<td>37</td>
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<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>38</td>
<td>37</td>
<td>40</td>
<td>39</td>
<td>154</td>
</tr>
</tbody>
</table>

Table 1 shows the number of successfully tested specimens in each group, indicating the distribution of specimens across different curing times and light powers.

After bonding, the teeth were stored in deionized water at 37°C for 72 hours. Brackets, chosen randomly, were debonded using a universal testing machine (Instron Model #1125, Instron Corp, Canton, Mass). In addition, the investigator was blinded to the group distribution. The specimens were placed in a jig that positioned the bracket base in a parallel relationship to the debonding force. Initially, 10 teeth were assigned to each group, but 6 specimens were damaged prematurely during the debonding process and had to be discarded (Table 1). The shear debonding force was applied to the bracket base in an occlusal-gingival direction at a crosshead speed of 0.5 mm/min. A load cell of 5 kN was used. The area of the bracket base was determined to be 9.81 mm² and was subsequently used to calculate the shear bond strength in megapascals (MPa).

The mode of bond failure of each specimen, chosen randomly, was examined under a light microscope (20×). Based on the amount of adhesive remaining on the tooth, an adhesive remnant index (ARI) score was assigned to each tooth. An ARI score of 0 indicated that no adhesive remained on the tooth in the bonding area; 1 indicated that less than half of the adhesive remained on the tooth; 2 indicated that more than half of the adhesive remained on the tooth; and 3 indicated that the entire adhesive remained on the tooth with a clear impression of the bracket mesh.

The two specimens with the greatest bond strengths were examined using a scanning electron microscope (SEM) to determine whether enamel fractures occurred with excessive bond strengths. Both specimens were viewed at magnifications of 20× and 500×.

Data displaying a normal distribution (parametric) was analyzed using a 2-way (4×4) analysis of variance (ANOVA). Ordinal data (nonparametric) was analyzed using the median test. A post hoc test (least squares difference) was also used. For this experiment, significance was determined as P < .05.

RESULTS

Mean shear bond strengths for each of the four curing times and powers are displayed in Table 2. The 2-way ANOVA revealed no significant interaction between time and power (P = .36) with respect to shear bond strength. In addition, there were no significant differences among time groups (P = .61) or among power groups (P = .09). Figures 1 and 2 show the shear bond strength relative to curing time and power, respectively. However, a post hoc test showed that there was a significant power effect (P = .02) between the 100-mW and 150-mW groups when the 200-mW and 250-mW groups were excluded (Table 2; Figure 2). Differences in shear bond strength between the remaining groups were not significant (P > .05). Of interest is the variability of the shear bond strengths, which is reported as the standard deviation of the means (Table 2).

Table 2 shows the mean shear bond strengths (MPa) and standard deviations (SD) in relation to curing time and light power.

**Figure 1.** Shear bond strength in relation to curing time.

**Figure 2.** Shear bond strength in relation to light power.

**Table 2.** Mean Shear Bond Strengths (MPa) and Standard Deviations (SD) in Relation to Curing Time and Light Power

<table>
<thead>
<tr>
<th>Time, s</th>
<th>Power, mW</th>
<th>100 Mean (SD)</th>
<th>150 Mean (SD)</th>
<th>200 Mean (SD)</th>
<th>250 Mean (SD)</th>
<th>Group Mean* (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>100</td>
<td>11.3 (6.5)</td>
<td>11.7 (7.9)</td>
<td>10.4 (7.1)</td>
<td>9.5 (5.8)</td>
<td>10.7 (6.6)</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>6.8 (4.7)</td>
<td>11.5 (9.4)</td>
<td>6.7 (3.6)</td>
<td>13.4 (7.5)</td>
<td>9.5 (7.0)</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>7.0 (3.7)</td>
<td>12.2 (6.5)</td>
<td>12.7 (7.4)</td>
<td>12.5 (7.6)</td>
<td>11.1 (6.7)</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>7.9 (4.8)</td>
<td>12.2 (7.9)</td>
<td>9.9 (4.6)</td>
<td>8.1 (4.9)</td>
<td>9.5 (5.8)</td>
</tr>
<tr>
<td>Group mean* (SD)</td>
<td></td>
<td>8.2 (5.1)</td>
<td>11.9 (7.6)</td>
<td>9.9 (6.1)</td>
<td>10.8 (6.6)</td>
<td></td>
</tr>
</tbody>
</table>

* Group means are the means for all specimens within a time or intensity group.
Relative and absolute frequencies for ARI scores in relation to curing time and power are listed in Tables 3 and 4, respectively. Cumulative ARI frequencies in relation to time and power can be seen in Figures 3 and 4, respectively. The median test revealed no significant differences in ARI scores in relation to time (P = .40); however, the ARI scores were significantly different in relation to power (P = .03). A post hoc test revealed that this difference was due to the 150-mW group, which had a much higher frequency of ARI scores of 0 than the remaining groups. SEM evaluation of the specimens with the greatest shear bond strengths showed no enamel fracture (Figures 5 through 8).

### DISCUSSION

Overall, the laser power (mW) did not show any significant effect on shear bond strength. This is similar to the findings of Talbot et al\(^\text{14}\) who showed no significant power effect between 200 mW and 300 mW. No differences were shown in the present study among higher powers, but post hoc analysis revealed a significant (P = .02) difference in bond strength between

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**Table 3. Absolute and Relative Frequency of ARI Scores in Relation to Curing Time**

<table>
<thead>
<tr>
<th>Time, s</th>
<th>ARI Score Frequency(^a,b,)* (%)</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
<td>59.5</td>
</tr>
<tr>
<td>10</td>
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<td>15</td>
<td>23</td>
<td>57.5</td>
</tr>
<tr>
<td>20</td>
<td>17</td>
<td>42.5</td>
</tr>
</tbody>
</table>

\(^a\) ARI, adhesive remnant index; Abs, absolute frequency; Rel, relative frequency.

\(^b\) ARI scores: 0, no adhesive remaining on tooth; 1, less than 50% of adhesive on tooth; 2, greater than 50% adhesive on tooth; 3, 100% of adhesive on tooth with clear impression of bracket base.

\(^*\) No significant differences among groups; P > .05.

**Table 4. Absolute and Relative Frequency of ARI Scores in Relation to Intensity**

<table>
<thead>
<tr>
<th>Power, mW</th>
<th>ARI Score Frequency(^a,b,) (%)</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>100**</td>
<td>17</td>
<td>45</td>
</tr>
<tr>
<td>150*</td>
<td>27</td>
<td>73</td>
</tr>
<tr>
<td>200**</td>
<td>18</td>
<td>45</td>
</tr>
<tr>
<td>250**</td>
<td>18</td>
<td>46</td>
</tr>
</tbody>
</table>

\(^a\) ARI, adhesive remnant index; Abs, absolute frequency; Rel, relative frequency.

\(^b\) ARI scores: 0, no adhesive remaining on tooth; 1, less than 50% of adhesive on tooth; 2, greater than 50% adhesive on tooth; 3, 100% of adhesive on tooth with clear impression of bracket base.

\(^*\) Significantly different among groups; P = .034.

\(^**\) Not significantly different among groups; P > .05.
the 100-mW and 150-mW groups. The shear bond strengths for the 150-mW group was 45% stronger than the 100-mW group, suggesting that 100 mW may not provide enough light power to penetrate the adhesive. In addition, it appears that a threshold value may exist between 100 mW and 150 mW that is sufficient to provide maximum bond strengths. Although the 150-mW group displayed the greatest shear bond strength; it was not significantly greater than the 200-mW and 250-mW groups.

A much higher frequency of low ARI scores was also found in the 150-mW group than in the other three intensity groups. This indicates a higher bond-failure rate at the enamel-adhesive interface (adhesive failure) as opposed to failures at the bracket-adhesive interface (adhesive failure) or failures within the adhesive (cohesive failure). In comparison to the other power groups, the 150-mW group displayed a stronger bracket-adhesive bond than an enamel-adhesive bond. When compared to the present 200-mW and 250-mW groups, Talbot et al. reported similar ARI scores at powers from 200 mW to 300 mW, with about 50% of the specimens having less than 10% of the adhesive remaining on the tooth following debonding.

Greater shear bond strengths will help to alleviate unwanted debonding during orthodontic treatment, but patient discomfort may arise and the possibility of enamel fracture exists when the brackets are removed. The SEM examination of the two specimens yielding the greatest shear bond strengths (28.8 MPa and 29.6 MPa) revealed no enamel fracture. This is a positive finding considering that these bond strengths approach 3 times the average bond strength found in the present study.

No significant time effect was found when curing from 5 to 20 seconds with this particular argon laser. Lalani and coworkers showed similar results using the ILT laser (ILT Systems, Salt Lake City, Utah) at 300 mW (similar adhesive, Transbond XT). They found no significant differences in shear bond strength for exposure times from 5 to 15 seconds. These findings suggest that the argon laser has the capability to maximally polymerize the adhesive in as little as 5 seconds, provided that the light power is sufficient. In addition to a power threshold, a time threshold most likely exists. Based on the present results, the time threshold needed to produce maximum shear bond strengths must be less than 5 seconds. It appears that
longer exposure times are not needed to produce greater bond strengths and that a point of diminishing returns may exist beyond this threshold. Further study is necessary to determine whether exposure times of less than 5 seconds produce similar results and to pinpoint a threshold value for exposure time.

ARI scores in relation to time did not significantly differ. About 40% to 60% of the specimens had an ARI
Figure 8. Scanning electron micrograph of specimen with greatest bond strength # 105 (500×).

score of 0, indicating that the predominant mode of failure was at the enamel-composite interface (adhesive failure). This is in contrast to other similar studies that reported higher ARI scores and more cohesive failures.12,13,15 The shear bond strengths measured in the present study show extreme variability, even though the means are comparable to other studies pertaining to the use of argon lasers in orthodontic bonding.12–14 Standard deviations were almost twice as large as reported in similar laser studies. It should be noted, however, that these previous studies used human enamel, which is qualitatively different than the bovine enamel used in the present study.12–14 Previous studies have used bovine enamel, and it has been recommended as a suitable substitute for human enamel, but this recommendation was based on the use of conventional halogen light sources.20,21

Another possible source of variability is the etching time used in the present study. On the basis of manufacturer’s suggested guidelines, each specimen was etched for 20 seconds, whereas the vast majority of the previous orthodontic bonding studies used a minimum of 30 seconds.13–15,21–24 Only one adhesive (brackets precoated with Transbond XT) was used in the present study, rendering it inappropriate to extrapolate this data to all orthodontic adhesives. In addition, although the precoated brackets were from the same batch, the possibility exists that there are minor differences between the consistency of ingredients from bracket to bracket that could lead to a higher variability in bond strength. Finally, in the current study, a 1.2-mm orthodontic light tip was used, which is much smaller than the typical 8-mm light tip. Although the orthodontic light tip provides very high intensities, the possibility remains that the diameter is not large enough to provide adequate exposure around the entire bracket; thus, a portion of the adhesive may not be sufficiently polymerized.

The results hold important clinical implications in terms of efficiency and effectiveness. Curing for 5 seconds using at least 150 mW of power with an argon laser provides the best results. Once this threshold is met, the use of longer curing times and/or higher light powers do not equate to better bond strengths with the argon laser. Moreover, the bond strengths obtained in the present study are greater than that which is considered to be clinically sufficient,17 suggesting that the argon laser can enhance efficiency in a clinical setting.

CONCLUSIONS
• Increasing the exposure time beyond 5 seconds has no cumulative effect on the shear bond strength of stainless-steel orthodontic brackets.
• Increasing the power setting beyond 150 mW has no cumulative effect on the shear bond strength of orthodontic brackets when using an argon laser.
• Using a combination of short exposure time and low power produces shear bond strengths equivalent to using longer exposure times and higher power.
• ARI scores are significantly lower (less adhesive re-
mainly on the enamel surface) when using 150 mW.
• Enamel fracture was not observed, even with greater than average bond strengths.

REFERENCES