Laser Activation of Endodontic Irrigants with Improved Conical Laser Fiber Tips for Removing Smear Layer in the Apical Third of the Root Canal

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Abstract

With a tube etching process, conical-ended optical fibers for middle infrared lasers that have lateral emissions can be produced, a feature of benefit for delivering laser energy onto the root canal walls. This study examined the ability of these improved laser tips when Er:YAG and Er,Cr:YSGG lasers were used in root canals in which thick smear layers had been created intentionally to provide a challenge for the laser system. Smear layer was assessed from scanning electron microscopy images with an objective digital method. Lasing improved the action of ethylene diamine tetraacetic acid with cetavlon (EDTAC) in removing smear layer. Conical fibers performed better than plain fibers, but there was no difference in performance between the 2 laser systems when matched for all other parameters. These results provide a “proof of concept” for lateral emitting fibers for endodontic procedures and illustrate the novel contribution of lasing to the action of EDTAC in dissolving smear layer. (J Endod 2008;34:1524–1527)

Key Words

Dentin ablation, erbium lasers, laser dentistry, smear layer

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tudies examining the removal of smear layer by using lasers delivered with conventional (forward-firing) optical fibers report a lack of consistency (1–3). We recently reported using a simple tube etching method to create long conical-ended fibers with lateral emissions, specifically for lasers used in endodontics (4). This method gives better control of fiber shape than earlier methods such as polishing or heating and pulling (5–7). We reasoned that such conical-ended fibers should provide improved debriding actions in the root canal when used to deliver energy from a water-absorbing middle infrared laser (Er:YAG or Er,Cr:YSGG) into an aqueous irrigant, because absorption of laser energy would induce shock waves into the irrigant (4, 8–10).

This study examined this concept by using, as the challenge, thick smear layers created by rotary instruments used with water. This is contrived but does provide an effective basis to assess debridement. Laser treatment was assessed in the apical third of the root canal, because this is the most challenging region to instrument. We used an objective digital image analysis method (11) to quantify the surface effects of lasing on smear layer.

Materials and Methods

Experimental Design

The study followed a matrix design. Extracted human teeth were stored in distilled water with 1% thymol and then radiographed by using a digital system (Sopro; Satelec, Italy) in 2 planes to exclude those with curved canals and other anomalies. A total of 150 teeth were selected, and their crowns were removed at the cementoenamel junction.

The roots were allocated randomly into 15 groups of 10 each. This number of groups allowed independent evaluation of the effects of fiber design (plain ended or conically modified fibers), irrigant (water, 3% hydrogen peroxide, or 15% EDTAC), and laser system (KaVo KEY 3 Er:YAG laser [Biberach, Germany] or Biolase Waterlase MD Er,Cr:YSGG laser [Irvine, CA]) (Table 1). Controls for the presence and absence of smear layer were included as well as nonirradiated controls (groups B, A, and C, respectively). The latter allowed the effect of EDTAC irrigant alone to be compared with the same irrigant with lasing.

For the Er:YAG laser, groups D1, D2, and D3 were treated with water, peroxide, and EDTAC, respectively, with a plain tip, whereas those in groups E1, E2, and E3 were treated with water, peroxide, and EDTAC, respectively, in the same manner but with the conical tip. For the Er,Cr:YSGG laser, there were an additional 6 groups (F1–F3, G1–G3), arranged in the same manner.

Lasers and Optical Fibers

The KEY3 laser (KaVo) was used at panel settings of 200mJ/pulse and 20 Hz (average power, 4 W), with a 400-μm (size ISO 40) endodontic fiber (either plain or conical). The Waterlase MD laser (Biolase) was used at panel settings of 1.25 W average power and 20 Hz (62.5 mJ/pulse) and was delivered into a 400-μm (MZ4) endodontic fiber (either plain or conical). No air or water spray was used. To prepare modified conical fiber ends, batches of fibers were etched with a 50% hydrofluoric acid solution in a tube etching technique, as described previously (4, 12), with 90 minutes and 160 minutes for the KaVo and Biolase fibers, respectively. The measured power output for both systems, determined with a laser power meter placed at a distance of 10 mm from the terminus of the fibers, was identical, 1.0 W
for the bare tips. This reduced to 0.75 W for the conical tips because of their greater lateral emissions (greater than 100 degrees divergence), which could not be captured by the power sensor used. The difference between panel settings and measured power with plain fibers reflects transmission losses, which were in line with the manufacturers’ specifications.

**Group A (Absence of Smear Layer)**

The working length was determined by measuring the length of a #8 K-file passively inserted into the canal until it was visible at the apex and then back-off 1 mm. Canals were prepared with rotary nickel-titanium (Ni-Ti) instruments to a working length 1 mm short of the apex to size F5 (0.50 mm) by using Protaper (Mailfer, Dentsply, Ballaigues, Switzerland) instruments. Canals were irrigated with 1% NaOCl followed by 3% H₂O₂ solution. After canal preparation was complete, the canals were flushed with 15% EDTAC solution (pH 7.2) for 2 minutes immediately followed by 1% NaOCl for 3 minutes (13). All irrigants were delivered with a 23-gauge needle. Previous scanning electron microscopy (SEM) studies have shown that this treatment results in minimal smear layer being present (11).

**Group B (Presence of Smear Layer)**

Canals were prepared as in group A, but with only distilled water used as an irrigant. Once the apical size was established to the size of an F5 instrument, canals were further instrumented circumferentially across all walls by using an F5 instrument for 3 cycles. Irrigation between instruments was with water. Pilot studies with SEM had shown that this treatment gave an even, thick deposit of smear layer across all walls of the canal in the apical third region.

**Group C (EDTAC without Irradiation)**

The canals were prepared as in group B, and the laser fiber was inserted but not activated in the presence of EDTAC. Treatment was undertaken for 10 passes of 5 seconds each, with an interval of 5 seconds between each, and fresh irrigation with EDTAC. Each pass was done at a fiber withdrawal rate of 1 mm/sec. Canals were then given a final rinse of distilled water to remove residual EDTAC. Hydrogen peroxide was not tested because this does not affect smear layer (13).

**Laser Groups (Groups D–G)**

Samples were first treated as in group B, with water as an irrigant, by using rotary files to create a thick smear layer. Laser fibers were placed into the appropriate irrigant solution in the root canal to a depth 1 mm short of the working length and then activated for 5 seconds. During lasing, the fiber was moved as in group C. Only the apical third of the root canal system was treated. Immediately after lasing, 1 mL of irrigant was flushed into the canal by using a 25-gauge needle during a period of 5 seconds. Lasing was then repeated for a total of 10 cycles of irrigation followed by lasing.

**SEM Examination**

Roots were dried on 24 hours at 21°C and then grooved longitudinally on their mesial and distal surfaces by using a diamond disk without water spray, with care being taken not to perforate into the canal. A chisel was placed into one of the grooves and then twisted gently to split the root into 2 parts. The samples were dried for an additional 24 hours and then sputter-coated with platinum and observed by SEM (JEOL 6400, Tokyo, Japan) at 13 kV. The entire area 2 mm from the apex was examined in each sample. The magnification used for smear layer analysis was 1000×. One representative SEM image at this magnification was recorded at a fixed distance of 2 mm from the working length for each sample. Images were recorded digitally in lossless TIFF format.

**Image Analysis**

SEM images were assessed with the objective digital method described previously (11) to determine the area of each image occupied by dentin tubules. Data were log-transformed to normalize the variance. Normality of the transformed data sets was confirmed by using the Kolmogorov-Smirnov test. Data sets were analyzed with analysis of variance and selected post hoc Tukey-Kramer multiple comparisons tests to explore the effect of laser system, fiber type, and irrigants. The analysis included comparison between lased samples and the various controls including sham irradiation.

**Results**

There was some degree of smear layer removal with all laser treatments used (Table 1, Fig. 1). As expected, there was minimal or

### Table 1. Area of Dentin Tubules

<table>
<thead>
<tr>
<th>Group</th>
<th>Irrigant</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>NaOCl + peroxide + EDTAC</td>
<td>6.37</td>
<td>4.14</td>
<td>13.5</td>
<td>2.11</td>
</tr>
<tr>
<td>Group B</td>
<td>Water</td>
<td>0.17</td>
<td>0.12</td>
<td>0.42</td>
<td>0.03</td>
</tr>
<tr>
<td>Group C</td>
<td>EDTAC</td>
<td>1.83</td>
<td>1.14</td>
<td>3.37</td>
<td>0.24</td>
</tr>
<tr>
<td>Group D</td>
<td>Water</td>
<td>0.72</td>
<td>0.56</td>
<td>2.1</td>
<td>0.25</td>
</tr>
<tr>
<td>Group E</td>
<td>EDTAC</td>
<td>0.75</td>
<td>0.35</td>
<td>1.57</td>
<td>0.34</td>
</tr>
<tr>
<td>Group F</td>
<td>Water</td>
<td>2.09</td>
<td>1.15</td>
<td>4.28</td>
<td>0.67</td>
</tr>
<tr>
<td>Group G</td>
<td>EDTAC</td>
<td>2.25</td>
<td>1.29</td>
<td>5.21</td>
<td>0.97</td>
</tr>
<tr>
<td>Group H</td>
<td>EDTAC</td>
<td>5.23</td>
<td>3.66</td>
<td>12.1</td>
<td>2.36</td>
</tr>
<tr>
<td>Group I</td>
<td>Water</td>
<td>0.56</td>
<td>0.26</td>
<td>1.05</td>
<td>0.061</td>
</tr>
<tr>
<td>Group J</td>
<td>Peroxide</td>
<td>1.13</td>
<td>0.52</td>
<td>1.77</td>
<td>0.35</td>
</tr>
<tr>
<td>Group K</td>
<td>EDTAC</td>
<td>8.14</td>
<td>5.2</td>
<td>19.58</td>
<td>2.45</td>
</tr>
<tr>
<td>Group L</td>
<td>Water</td>
<td>2.25</td>
<td>0.36</td>
<td>2.72</td>
<td>1.4</td>
</tr>
<tr>
<td>Group M</td>
<td>EDTAC</td>
<td>2.58</td>
<td>1.07</td>
<td>3.99</td>
<td>0.85</td>
</tr>
<tr>
<td>Group N</td>
<td>EDTAC</td>
<td>9.86</td>
<td>5.63</td>
<td>23.12</td>
<td>2.43</td>
</tr>
</tbody>
</table>

EDTAC, ethylene diamine tetraacetic acid with cetavlon.

Data presented are the percentage area of the root canal wall in the apical third region occupied by patent dentin tubules from N = 10 samples per group. Group A, Ni-Ti with EDTAC irrigant (control for lack of smear layer); group B, Ni-Ti with water irrigant (positive control for the presence of smear layer); group C, EDTAC with sham irradiation (control for the passive effect of EDTAC). Laser treatments are summarized as follows: group D, Er:YAG laser with plain fiber; group E, Er:YAG laser with conical modified fiber; group F, Er,Cr:YSGG laser with plain fiber; group G, Er,Cr:YSGG laser with conical modified fiber.
no smear layer in group A in which rotary Ni-Ti instruments were used with 1% NaOCl and 3% H₂O₂ irrigants followed by final flushing with EDTAC and NaOCl. In contrast, in group B in which only distilled water was used as an irrigant, thick homogenous smear layer was present in the apical third region.

In the nonirradiated group (group C), the presence of 15% EDTAC as an irrigant in the canal for 120 seconds gave a modest level of smear layer removal, without additional laser treatment. By comparing the sham-irradiated samples with lased samples, it was apparent that lasing improved the action of EDTAC when this solution was allowed to remain in the canal for the same treatment time of 2 minutes.

Considering the independent variables (Table 2), the conical fiber design performed better than plain fibers when matched for the same laser system and the same irrigant. In fact, the modified conical tip used with any of the 3 irrigants gave smear layer removal that was statistically identical to the “clean” controls in group A. EDTAC was better than both peroxide and water when matched for the same laser and same fiber design. There was no statistically significant difference in performance between the 2 laser systems.

**Figure 1.** Apical third of the root canal after treatment with the Er, Cr:YSGG laser with a plain fiber (A, C) or a conical fiber (B, D), with hydrogen peroxide (A, B) or EDTAC (C, D) as the irrigant fluid. All images were recorded at 1000 x. Scale bars indicate 10 μm. Note the reduced smear layer with the conical tip (right side images vs left side images) and the greater opening of the tubules with EDTAC (lower images vs upper images).

**TABLE 2.** Statistical Analyses

<table>
<thead>
<tr>
<th>Variable</th>
<th>Groups</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of fiber design</td>
<td>E1 &gt; D1***; E2 &gt; D2***; E3 = D3; G1 &gt; F1***; G2 &gt; F2*; G3 = F3</td>
<td>Conical fiber is better when matched for the same laser and same irrigant.</td>
</tr>
<tr>
<td>Effect of irrigant</td>
<td>D3 &gt; D1 = D2***; E3 &gt; E1 = E2*; F3 &gt; F1 = F2***; G3 &gt; G1 = G2**</td>
<td>EDTAC is better than both peroxide and water when matched for the same laser and same fiber design.</td>
</tr>
<tr>
<td>Effect of laser</td>
<td>D1 = F1; D2 = F2; D3 = F3; E1 = G1; E2 = G2; E3 = G3</td>
<td>No difference between lasers when matched for the same fiber design and same irrigant.</td>
</tr>
<tr>
<td>Comparison with conventional Ni-Ti and EDTAC (group A, lack of smear layer)</td>
<td>A = D3 &gt; D1 = D2***; A = E2 = E3 &gt; E1; A = F3 &gt; F1 = F2***; A = G1 = G2 = G3</td>
<td>Conical tip removes smear layer to leave a final surface similar to Ni-Ti + EDTAC.</td>
</tr>
<tr>
<td>Laser activation of EDTAC versus passive EDTAC</td>
<td>D3 = E3 = F3 = G3 &gt; C**</td>
<td>Lasing improves the action of EDTAC for the same treatment time.</td>
</tr>
<tr>
<td>Effect of treatments versus control for the presence of smear layer (group B, Ni-Ti + water)</td>
<td>B &lt; all other groups**</td>
<td>All treatments offer a level of smear layer removal.</td>
</tr>
</tbody>
</table>

EDTAC, ethylene diamine tetraacetic acid with cetavlon.

*p < 0.05

**p < 0.01

***p < 0.001
**Discussion**

The working hypothesis for this study that conical tips should outperform conventional designs was confirmed, with the contrived but standardized situation of a thick smear layer created by conventional rotary instruments used with water. This can be attributed to the more even irradiation of the irrigant fluid and of the canal walls with these tips. Such tips are also likely to be easier to navigate into curved canals, although this aspect was not examined directly in the present study because all teeth used had straight roots. We are examining the ability of conical fibers to negotiate curved canals in a separate study.

Laser treatment when combined with EDTAC was able to remove the intentionally created thick smear layers and give a final result as clean as when conventional Ni-Ti instruments were used with EDTAC. This suggests that pulsed middle infrared lasers used with modified conical fibers might be useful for debridement in the apical third of the root canal.

Although the contribution of smear layer to long-term outcomes in endodontic treatment remains under debate, the results of the present study demonstrate that the debriding action of middle infrared laser energy is much better when delivered through conical modified fibers than unmodified conventional optical fibers when used with the same irrigant. The divergent laser energy can interact with the canal walls, causing ablation by photomechanical effects (9, 14, 15). Previous work by our group (4) and others (10) has shown that pulsed middle infrared lasers create shock waves in aqueous solutions in root canals. The conical shape influences the configuration of this shock wave, which might further enhance its action on debris.

An important finding in this study was that laser treatment delivered with EDTAC improved the effectiveness of EDTAC in smear layer removal, as seen by comparing the lased and nonirradiated groups, where EDTAC was present for the same time period. Hydraulic stresses created in the EDTAC solution by lasing might agitate it, increase its ambient temperature, and increase its penetration into the smear layer and any open tubules.

**Conclusion**

Conical fiber tips performed better than plain fibers for removal of smear layer when matched for the same laser system and the same irrigant. Additional studies are needed to establish the usefulness of these modified fibers in other endodontic applications such as enlarging the canal or canal disinfection.

**Acknowledgments**

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**References**