Effectiveness of Laser-Assisted Irrigation and Passive Ultrasonic Irrigation Techniques on Smear Layer Removal in Middle and Apical Thirds

L. B. AYRANCI,1 H. ARSLAN,1 M. AKCAY,2 I. D. CAPAR,3 T. GOK,3 AND G. SAYGILI3

1Department of Endodontics, Faculty of Dentistry, Ataturk University, Erzurum, Turkey
2Department of Pedodontics, Faculty of Dentistry, Katip Celebi University, Izmir, Turkey
3Department of Endodontics, Faculty of Dentistry, Katip Celebi University, Izmir, Turkey

Summary: The purpose of this study was to investigate the evaluation of laser-assisted irrigation (LAI) on the removal of the smear layer as compared to passive ultrasonic irrigation (PUI). Forty-eight single-rooted, upper-central incisor teeth were selected and prepared with ProTaper rotary instruments up to size #40 (F4) at the working lengths. Specimens were divided into four groups, as follows: (a) PUI with 5 mL of 2.5% NaOCl for 60 s; (b) PUI with 2.5 mL of 17% EDTA and 2.5 mL of 2.5% NaOCl each for 30 s; (c) LAI with 5 mL of 2.5% NaOCl for 60 s; and (d) LAI with 2.5 mL of 17% EDTA and 2.5 mL of 2.5% NaOCl each for 30 s. In the PUI groups, the ultrasonically activated file was inserted 1 mm short of the working length, but in the LAI groups, the fiber tip was applied into the pulp chamber. LAI in the pulp chamber with the combination of 17% EDTA and 2.5% NaOCl removed more of the smear layer than the other groups (p < 0.018). LAI in the pulp chamber better removed the smear layer than LAI applied similarly but without EDTA or PUI with the same NaOCl and EDTA combinations using an ultrasonically activated file inserted 1 mm short of the working length.

Introduction

During the chemo-mechanical preparation of a root canal, either by hand or using rotary instruments, debris, and a smear layer are created (Violich and Chandler, 2010). The smear layer is composed of organic and inorganic components, including vital or necrotic pulp tissue, microorganisms, saliva, blood cells, and tooth structure (Czonstkowski et al., ’90). It has an amorphous and irregular appearance and consists of two separate layers. The first layer is superficial and loosely adherent to the underlying dentine, while the other is packed into dentinal tubules for distances up to 50 μm (Aktener et al., ’89; Cameron, ’83). Also, it can be infected and act as a harbor for bacteria and bacterial products (McComb and Smith, ’75; Pashley, ’84). Moreover, the presence of a smear layer can negatively affect the diffusion of intra-canal medicaments and the adhesion of root canal sealers (Bystrom and Sundqvist, ’85; Gencoglu et al., ’93; Saleh et al., 2002; Yang and Bae, 2002); therefore, the smear layer should be removed. However, irrigating solutions may be inefficient in removing the smear layer, especially from the apical thirds of root canals (Mancini et al., 2009; Torabinejad et al., 2003). Previous reports have proposed, improved irrigation agitation methods to address this issue (Guarisi et al., 2002). Recently, agitation of irrigating solutions with laser devices has become popular (de Groot et al., 2009; de Moort et al., 2009; Moon et al., 2012).

In a novel laser-assisted irrigation (LAI) technique using erbium lasers, the laser tip is placed into the pulp chamber (DiVito and Lloyd, 2012). Divito et al. (2012) used this technique with a radial and stripped fiber tip at a subablative power setting (0.3 W), which, they demonstrated, results in significantly better removal of the smear layer as compared to saline water irrigation. Likewise, by using a plain fiber tip to activate the irrigating solution in the pulp chamber Peeters and
Suardita (2011) demonstrated that the use of a laser with a plain fiber tip can produce cavitation in the irrigant and has potential as an improved alternative method for smear layer removal.

Passive ultrasonic irrigation (PUI) uses an ultrasonically activated file to energize the irrigant in the canal and to create acoustic streaming (Ahmad et al., ‘87; Klyn et al., 2010). To improve the root canal cleaning, irrigants should touch the canal walls (Zehnder, 2006). The conventional needle irrigation technique does not provide complete cleaning of the root canal system (Villas-Boas et al., 2011). Passive ultrasonic activation is able to spoil the endodontic biofilm and help irrigants better penetrate along the root canal walls (Ahmad et al., ’87; Gu et al., 2009). The use of PUI combined with sodium hypochlorite removed more debris and smear layer compared to syringe irrigation (Al-Jadaa et al., 2009; Townsend and Maki, 2009).

The aim of the present study was to investigate the effectiveness of LAI with 2.5% NaOCl alone and in combination with 17% EDTA on the smear layer in the middle and apical thirds of the root canals as compared to that of PUI (with and without EDTA). The null hypothesis was that no statistically significant differences would exist between the LAI and PUI techniques.

Materials and Methods

Preparation of the Specimens

A total of 48 single-rooted, non-caries human upper central incisor teeth with completed apices were used for this study. The teeth, extracted for reasons unrelated to this study, were immersed in 0.5% Chloramine-T solution (Merck, Germany) for 48 h for disinfection. Soft tissue and calculus were mechanically removed from the root surfaces with a periodontal scaler. The teeth were verified radiographically as having a single root canal without calcification. The exclusion criteria comprised those teeth with more than a single root canal and apical foramen, root canal treatment, internal/external resorption, immature root apices, caries/cracks/fractures on the root surface, and/or root canal curvature of more than 10 degrees. The teeth were then stored in distilled water at room temperature until use. The incisal edge of each specimen was flattened using a bur under water coolant to obtain a standardized tooth length of 19 mm.

A standard coronal access cavity preparation was performed, and the working length was defined by subtracting 1 mm from the point at which a size #10 stainless steel K-file (Dentsply Maillefer, Ballaigues, Switzerland) tip protruded from the apical foramen. Root canals were prepared with ProTaper rotary instruments (Dentsply Maillefer) up to size #40 (F4) at the working lengths. Between instrument changes, 2 mL 2.5% mL of NaOCl was used. All irrigating procedures were performed with a 27 gauge blunt-tip needle (Ultradent, Utah, UT). During irrigation, the needle was placed at a distance of 1 mm from the working length and then moved back and forth.

To simulate the clinical situation, a closed-end system was created by coating each root apex with soft wax. During the coating of the root, a ProTaper F4 Gutta-Percha point (Dentsply Maillefer) was introduced into the root canal to hinder the penetration of wax into the root canal system (Alfredo et al., 2009; Pedulla et al., 2012). The specimens were then divided randomly into four groups (n = 12) and irrigated as follows (Table I):

- **Passive Ultrasonic Irrigation 1 (PUI 1):** In this group, a single use of 5 mL of 2.5% NaOCl was ultrasonically activated using a smooth ultrasonic file (15/02). The root canal and pulp chamber were first filled with the irrigating solution, then the ultrasonic tip was inserted 1 mm short of the working length and the ultrasonic device (Anthos u-PZ6, Imola, Italy) was activated for 60 s at 25% power. During the activation procedure, the irrigation was gently continued through the pulp chamber.

- **Passive Ultrasonic Irrigation 2 (PUI 2):** In this group, 2.5 mL of 17% EDTA and 2.5 mL of 2.5% NaOCl were ultrasonically activated for 30 s each. The procedures for each irrigating solution were repeated as for those used with the PUI 1 group. Before the activation of the NaOCl, the EDTA irrigating solution was suctioned from the root canals.

- **Laser-Assisted Irrigation 1 (LAI 1):** In this group, 5 mL of 2.5% NaOCl was activated using a laser for 60 s. The water and air on the laser system were turned off. The root canal and pulp chamber were filled with 2.5% NaOCl, and then a 14-mm-long, 300-micron fiber tip was inserted into the pulp chamber and

<table>
<thead>
<tr>
<th>Group</th>
<th>Irrigant</th>
<th>Activation</th>
<th>Total activation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>PUI 1</td>
<td>5 mL 2.5% NaOCl</td>
<td>Ultrasonic</td>
<td>60 s</td>
</tr>
<tr>
<td>PUI 2</td>
<td>2.5 mL 17% EDTA + 2.5 mL 2.5% NaOCl</td>
<td>Ultrasonic</td>
<td>60 s</td>
</tr>
<tr>
<td>LAI 1</td>
<td>5 mL 2.5% NaOCl</td>
<td>Laser</td>
<td>60 s</td>
</tr>
<tr>
<td>LAI 2</td>
<td>2.5 mL 17% EDTA + 2.5 mL 2.5% NaOCl</td>
<td>Laser</td>
<td>60 s</td>
</tr>
</tbody>
</table>
applied with 0.3 W, 15 Hz, and 20 mJ per pulse. A total of 5 mL of 2.5% NaOCl was applied through the pulp chamber.
Laser-Assisted Irrigation 2 (LAI 2): In this group, 2.5 mL of 17% EDTA and 2.5 mL of 2.5% NaOCl were activated using the laser for 30 s each. The procedures employed for LAI 1 were applied here also for each irrigating solution. Before the activation of the NaOCl, the EDTA irrigating solution was suctioned from the root canals.

Laser System

An Er: YAG laser system (Fidelis AT, Fotona, Ljubljana, Slovenia) was used with an emission wavelength of 2940 nm. This laser system has a maximum 20-W source power with a 50-Hz frequency, and it can deliver energy in pulsed mode with a pulse duration of between 0.005 msec and 1 msec. In the present study, a 14-mm-long conical, cylindrical (tapered) 300-μm fiber tip was used with a 50-msec pulse duration (SSP mode).

The flow rate was approximately 0.04 mL/s for all groups. The root canals were finally irrigated using 10 mL of distilled water and then dried with absorbent paper points. The waxes around the roots were removed, and the specimens were stored in 2.5% glutaraldehyde solution buffered with phosphate for 24 h to obtain fixation. The specimens were rinsed with tap water, and two parallel grooves on the buccal and palatal surfaces were made using a diamond disk followed by cleaving into the groove with a fine chisel. The specimens were carefully split into two halves by twisting the chisel, taking care not to force debris into the canal. The specimens were dehydrated using a series of graded ethanol solutions (70, 80, 90, and 100%) respectively for each 24 h period and then stored at 37˚C for 48 h. One half of each specimen was selected and coated with a gold-palladium layer (Polaron SC502; Fisons Instruments, Ipswich, England). Next, the specimens were analyzed using a JEOL JSM 6400 scanning electron microscope (JEOL USA, Peabody, MA). Two photomicrographs were taken from the middle (7 mm from the apex) and apical thirds (2 mm from the apex) of each specimen at a ×1,500 times magnification.

The smear layer scores for each tooth were recorded by two observers (Kappa value = 0.870). The criteria employed for the smear layer was as follows (Hulsmann et al., ’97):

1. No smear layer, dentinal tubules open.
2. Small amount of smear layer, some dentinal tubules open.
3. Homogenous smear layer covering the root canal wall, only few dentinal tubules open.
4. Complete root canal wall covered by a homogenous smear layer, no open dentinal tubules.
5. Heavy, non-homogenous smear layer covering the complete root canal wall.

The differences in the smear layer scores among the different groups were analyzed with Kruskal–Wallis and Mann–Whitney U tests with Bonferroni correction (p = 0.018). All statistical analyses were performed using IBM SPSS Statistics 20 software (IBM SPSS Inc., Chicago, IL).

Results

The frequency scores for the smear layer are detailed in Table II. In the LAI groups and the PUI groups with EDTA and NaOCl, the middle thirds had a lesser smear layer as compared to the apical thirds of the root canals (p < 0.001). In the PUI group with NaOCl, no significant difference was observed between the middle and apical thirds. Neither LAI nor PUI with NaOCl completely removed the smear layer from the root canal.

The mean and standard deviation scores for smear layer removal according to the root canal thirds are detailed in Table III. For both the middle and apical thirds of the root canals, the Kruskal–Wallis test showed statistically significant differences between the groups (p < 0.001). The Mann–Whitney U test revealed that LAI with the combination of EDTA and NaOCl in the

<table>
<thead>
<tr>
<th>Table II</th>
<th>Frequency of smear layer scores for groups and thirds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Apical scores</td>
</tr>
<tr>
<td>Groups</td>
<td>1</td>
</tr>
<tr>
<td>PUI 1</td>
<td>0</td>
</tr>
<tr>
<td>PUI 2</td>
<td>0</td>
</tr>
<tr>
<td>LAI 1</td>
<td>0</td>
</tr>
<tr>
<td>LAI 2</td>
<td>2</td>
</tr>
</tbody>
</table>

PUI 1 passive ultrasonic irrigation of NaOCl; PUI 2 passive ultrasonic irrigation of NaOCl and EDTA; LAI 1 laser-assisted irrigation with NaOCl; LAI 2 laser-assisted irrigation with NaOCl and EDTA; Score 1: No smear layer, dentinal tubules open; Score 2: Small amount of smear layer, some dentinal tubules open; Score 3: Homogenous smear layer covering the root canal wall, only few dentinal tubules open; Score 4: Complete root canal wall covered by a homogenous smear layer, no open dentinal tubules; Score 5: Heavy, non-homogenous smear layer covering the complete root canal wall.
pulp chamber removed the smear layer from both the middle and apical thirds of the root canals more effectively than PUI with the EDTA and NaOCl combination (PUI 2) \((p < 0.018)\). PUI with the EDTA and NaOCl combination (PUI 2) removed more smear layer than both LAI and PUI with NaOCl alone (no EDTA, the LAI 1 and PUI 1 groups) \((p < 0.018)\). LAI and PUI with NaOCl alone showed the lowest scores and were ineffective in removing smear layer (Fig. 1).

### Discussion

The main function of the root canal irrigants is to clean the root canal system during the shaping and enlargement procedure (Giardino et al., 2006). Previous studies have demonstrated that the widely used needle irrigation technique is not efficient in the apical third of the root canal (Torabinejad et al., 2003; Mancini et al., 2009). This conventional technique administers solutions at a distance of only 0–1.1 mm beyond the needle tip (Munoz and Camacho-Cuadra, 2012). However, root canal irrigants should be in contact with root canals to improve the effectiveness of these solutions in the apical region (Zehnder, 2006). For this reason, acoustic and hydrodynamic activation of the irrigants have been researched (Weller et al., ‘80). Thus, activation of the irrigating solution with lasers is being used in endodontic therapy (George et al., 2008). Recently, laser irrigation activation performed in the pulp chamber has been introduced. Therefore, the aim of the present study was to investigate the effectiveness of LAI with 2.5% NaOCl alone and in combination with 17% EDTA on the smear layer removal in the middle and apical thirds of the root canals as compared to PUI (also with 2.5% NaOCl alone and in combination with 17% EDTA).

The results of the present study show that removal of the smear layer was better in the middle third than in the apical third of the root canal. This finding is in accordance with those of previous studies (Arslan et al., 2013; Perez-Heredia et al., 2006). The ineffectiveness of techniques in removing the smear layer from
the apical thirds can be explained by the fact that the particular apical is smaller in size than the other thirds and that the a greater extent of tubular sclerosis occurs in the apical third (Ram, ’77; Abou-Rass and Patonai, ’82; Druittman and Stock, ’89; Paque et al., 2006; Teixeira et al., 2005).

Pertinently, the results of the present study also showed LAI with the combination of NaOCl and EDTA to be superior to PUI with the combination NaOCl and EDTA in removing the smear layer. Thus, the null hypothesis that no statistically significant differences would exist between the LAI and PUI techniques was rejected.

Cavitation is the foundation of the LAI technique with the Er: YAG system. Bubbles, the formation of an empty space in a liquid, occur in the cavitation process. When Er: YAG laser irradiation is absorbed by the irrigating solution, the energy applied causes evaporation. The vapor bubble starts to expand and form a void in front of the laser light (Brugnera et al., 2003; Kivanc et al., 2008). Matsumoto et al. (2011) observed the second cavitation bubble at the bottom when the laser tip was inserted 2 and 5 mm short of the bottom of an artificial glass root canal model. Therefore, they suggested that it is not always necessary to insert the laser tip up to the apex, because the cavitation bubbles also assist in cleaning the apical region. This finding has also been confirmed in the present study.

Divito et al. (2012) prepared root canals of up to size 20.06 using rotary files and compared saline water with laser-activated distilled water in removal of the smear layer. According to the results of their study, the laser activated water was found to be superior to single saline water irrigation. The authors revealed that the apex can be reached by the irrigants without the laser tip being close to the apex, which allows a less invasive preparation. Despite this, some studies reported that an increase in root canal taper and apical preparation size improves the irrigant replacement (Boutsiosiakis et al., 2010a,b). Therefore, contrary to the aforementioned study, a minimally invasive preparation size (20.06) was not used in the present study; here, the root canals were prepared with ProTaper rotary files up to size #40.

In another study, the authors evaluated the smear layer removal and endodontic wall cleanliness after the EndoActivator system, the EndoVac system and the PUI system were used for irrigation. The PUI system showed less smear layer removal in the apical third, probably because of the contact between the ultrasonic file and the root canal walls and insufficient time for activation (1 min) (Mancini et al., 2013). Our study, which is in agreement with the previous study, revealed that PUI with the EDTA and NaOCl combination removed less smear layer than LAI with the combination of EDTA and NaOCl in both the middle and apical thirds of the root canals.

Peeters and Suardita (2011) prepared root canals using hand files and, after preparation, irrigated root canals with 5 mL of 17% EDTA to remove the smear layer. The laser activation procedures were then performed on the teeth using a 600-μm fiber-tip handpiece fitted to an Er,Cr:YSGG laser. Panel settings in that study of 1 W and 35 Hz were used to activate 5 mL of 17% EDTA in the pulp chamber. It was reported that the plain fiber in the pulp chamber can drive the irrigation solution to the tip of the canal without harming the apical tissue. In the present study, the finding of the aforementioned study was confirmed with a lower panel setting (0.3 W and 15 Hz). Furthermore, and contrary to Peeters and Suardita (2011) in the present study, EDTA was not used at any stage of the procedure until activation (by laser or file), in order not to affect the inorganic component smear layer that was created.

Ahmetoglu et al. (2014) evaluated the effectiveness of the apical negative pressure irrigation (EndoVac), passive ultrasonic irrigation (PUI), and conventional needle irrigation (CI) systems on the smear layer. They reported that no matter which irrigation system was used, the use of NaOCl alone failed to remove the smear layer and in the NaOCl/EDTA combination groups, the smear layer was removed partially or completely. This study revealed that to remove the smear layer, regardless of the technique, the EDTA solution should be used for the final irrigation in the root canal. In the present study, we confirmed the previous study that in both PUI and LAI techniques, NaOCl/EDTA combination groups removed more smear layer than NaOCl groups. In the present study also, distilled water was not activated by the laser as in Divito et al. (2012); rather, LAI with a single application of NaOCl was performed. In addition, both NaOCl and the combination of NaOCl and EDTA activated using both LAI and PUI techniques was employed in the current study, to test whether the single use of NaOCl might completely remove the smear layer. According to the results, neither PUI nor LAI with a single NaOCl use was effective in the removal of the smear layer. However, the combination of either PUI or LAI with the EDTA and (single-use) NaOCl combination did remove more smear layer from root canals than the PUI and LAI with NaOCl. These results are harmonious with previous studies (Goldman et al., ’81; Haznedaroğlu and Ersev, 2001; Gurbuz et al., 2008; Arslan et al., 2013).

Within the limitations of this study, it can be concluded that the LAI in the pulp chamber with the combination of (single-use) 2.5% NaOCl and 17% EDTA better removes the smear layer from the middle and apical thirds of the root canals than PUI with the (single-use) 2.5% NaOCl and 17% EDTA combination (and also better than these techniques employed without EDTA, which are ineffective).
Acknowledgment

The authors deny any financial affiliations related to this study or its sponsors.

References


