Effect of photon-initiated photoacoustic streaming on removal of apically placed dentinal debris

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Abstract

Aim To compare the efficacy of photon-induced photoacoustic streaming (PIPS) technique with conventional, sonic and ultrasonic irrigation on the removal of apically placed dentinal debris from an artificial groove created in a root canal.

Methodology Root canal preparation was performed up to size 40 on 48 extracted single-rooted teeth using ProTaper rotary instruments. The specimens were then split longitudinally, and a standardized groove was prepared in the apical part of each segment. Each groove was filled with dentinal debris mixed with 5% NaOCl. Each tooth was reassembled and irrigated as follows: (i) conventional irrigation with 1% NaOCl, (ii) sonic, (iii) ultrasonic irrigation, and (iv) PIPS. The root segments were disassembled, and the amount of remaining dentinal debris was evaluated under a stereomicroscope at 20× magnification, using a four-grade scoring system. The data were evaluated statistically using Kruskal–Wallis and Mann–Whitney U-tests with a 95% confidence level (P = 0.05).

Results Photon-induced photoacoustic streaming removed significantly more dentinal debris than conventional irrigation (P < 0.001), sonic irrigation (P < 0.001) or ultrasonic irrigation (P = 0.005). There was no significant difference between sonic and ultrasonic irrigation (P = 0.377).

Conclusions Photon-induced photoacoustic streaming was more effective than conventional, sonic and ultrasonic irrigation in the removal of apically placed dentinal debris.

Keywords: EndoActivator, endodontics, photoacoustic streaming, PIPS, sonic, ultrasonic.

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Introduction
The goal of biomechanical preparation is to clean, shape and disinfect the root canal system. However, chemomechanical preparation leaves untouched zones, debris, the smear layer and microorganisms and their by-products, which can result in persistent inflammation (Vertucci 1984, Wu & Wesselinck 2001b, Wu et al. 2001a). That is why irrigation plays an essential role in root canal treatment. However, because irrigating solutions can be ineffective in removing material from the root canal walls (Torabinejad et al. 2003, Mancini et al. 2009), improved irrigation agitation methods such as sonic and ultrasonic devices have been proposed (Guerisoli et al. 2002). Recently, agitation of irrigants using lasers has gained popularity (De Moor et al. 2009, de Groot et al. 2009, Moon et al. 2012).

A novel laser agitation technique, photon-induced photoacoustic streaming (PIPS), has been proposed. This technique differs from other agitation techniques in that only the tip is placed into the canal orifice...
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Previous studies have shown that large amounts of debris remain in root canal irregularities after the use of conventional syringe irrigation (Goodman et al. 1985, Wu & Wesselink 2001b). If these untouched zones with debris remaining after conventional techniques are not well cleaned, it is not possible to provide direct contact for the medicaments with bacteria or to allow the irrigating solution to reach inaccessible areas. A toothbrush was used to remove debris from the root halves and grooves. A final flush was applied using 5 mL of 17% EDTA for 1 min and 5 mL of 2.5% NaOCl for 1 min. The root canals were then dried with paper points.

**Dentinal debris application**

To obtain dentine powder, a number of teeth were split longitudinally and dentinal debris was obtained using round burs. The debris was mixed with 5% NaOCl 5 min before use. The standardized grooves were filled with dentinal debris using a spreader. The root halves were reassembled, and all gaps along the tooth and the apices were sealed with wax to prevent the overflow of the irrigating solution and to create a closed-end channel so as to obtain a vapour lock effect (Alfredo et al. 2009, Pedulla et al. 2012). The specimens were divided randomly into four groups (n = 12) and irrigated as follows:

Conventional irrigation: 6 mL of 1% NaOCl via a size 27 gauge blunt-tip needle (Ultradent, South Jordan, UT, USA) was used for 1 min. The needle was inserted into the root canal within 1 mm of the working length without binding. The flow rate of the irrigating solution was 0.1 mL s$^{-1}$.

**Sonic irrigation:** 0.5 mL of 1% NaOCl was flushed into the root canal using a needle: a red (size 25, .04 taper) sonic tip was then inserted 2 mm short of the working length, and the sonic handpiece (EndoActivator; Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) was activated for 1 min at 10 000 cycles min$^{-1}$ (Klyn et al. 2010). During the activation procedure, irrigation was gently continued through the root canal opening using 5.5 mL of irrigating solution.

**Ultrasonic irrigation:** 0.5 mL of 1% NaOCl was placed into the canal as in the sonic group; a smooth ultrasonic file (size 15, .02 taper) was then inserted into the canal as in the sonic group.
1 mm short of the working length (Lee et al. 2004, van der Sluis et al. 2005, Rodig et al. 2010), and the ultrasonic device (Anthos u-PZ6, Imola, Italy) was activated for 1 min at 25% power. During activation, irrigation was gently continued through the root canal opening using 5.5 mL of irrigating solution.

**Pips:** dentinal debris was removed using the laser irradiation protocol, which was performed by an Er/YAG laser with an emission wavelength of 2940 nm (Fidelis AT, Foton, Ljubljana, Slovenia). A 14-mm-long and conical, cylindrical (tapered) 300-µm fibre tip was applied at 0.3 W, 15 Hz and 20 mJ per pulse. The water and air on the laser system were turned off. Then, 0.5 mL 1% NaOCl was placed into the root canal, and the optical fibre was placed approximately 1 mm below the root canal orifice. When the irrigating solution in the coronal reservoir decreased, the supplemental NaOCl was applied through the root canal opening. The laser activation was continued during the placement of irrigant. The total activation time was 1 min, and the total volume of 1% NaOCl was 6 mL.

For all groups, the total volume of 1% NaOCl was 6 mL and the exposure time to 1% NaOCl was 1 min. The root canals were dried with paper points, and the roots were disassembled to evaluate the removal of the dentinal debris. Digital images at 20× magnification were obtained using a stereomicroscope (Olympus BX43; Olympus Co., Tokyo, Japan) attached to a digital camera and were transferred to the computer. The digital images were coded to avoid identifying the specimens. Two calibrated observers were blinded to the technique used to remove dentinal debris. The amount of dentinal debris remaining in the grooves was scored using the following scoring system, described by van der Sluis et al. (2007):

- 0: Groove was empty;
- 1: Dentinal debris was present in less than half of the groove;
- 2: Dentinal debris covered more than half of the groove;
- 3: The groove was completely filled with dentinal debris;

Photographs were evaluated by the observers 1 week later, and the Kappa test was used to analyse interexaminer agreement. The differences in the dentinal debris scores among the different groups were analysed with Kruskal–Wallis and Mann–Whitney U-tests. Testing was performed at the 95% confidence level (P = 0.05). All statistical analyses were performed using IBM® SPSS® Statistics 20 software (IBM SPSS Inc., Chicago, IL, USA).

**Results**

The scores for the dentinal debris remaining in the grooves for all groups are shown in Fig. 1. The Kruskal–Wallis test revealed significant differences between

![Figure 1 Distribution of scores for removal of apically placed dentinal debris after agitation with different protocols according to Observers 1 and 2.](image-url)
the groups ($P < 0.001$). The Mann–Whitney U-test revealed that PIPS removed more dentinal debris than conventional irrigation ($P < 0.001$), sonic irrigation ($P < 0.001$) and ultrasonic irrigation ($P = 0.005$). In the PIPS group, the majority (75%) of specimens were assessed to be totally free from debris. The percentages of complete removal of dental debris (Score 0) for conventional, sonic and ultrasonic irrigation techniques were 0%, 8.3% and 25%, respectively. Conventional irrigation had the most remaining debris, although there were no significant differences between conventional irrigation and sonic ($P = 0.309$) and ultrasonic irrigation ($P = 0.061$). There was also no significant difference between sonic and ultrasonic irrigation ($P = 0.377$). Intraindividual reproducibility was 98% (47/48) for each examiner. The reliability between the examiners was good ($\kappa$ value = 0.971), and the difference between the matched scores never exceeded one unit.

**Discussion**

This study compared the removal of apically placed dentinal debris with conventional, sonic and ultrasonic irrigation to that obtained using PIPS. PIPS removed more debris compared with the other agitation techniques. Therefore, the null hypothesis that there is no difference between PIPS and the other irrigation techniques can be rejected.

DiVito et al. (2012b) demonstrated that laser-activated irrigation using PIPS tips resulted in a significantly better cleaning of the root canal walls in comparison with the conventional irrigation procedures. In a recent study, Lloyd et al. (2013) also showed that laser-activated irrigation using PIPS tips eliminated organic debris from canal isthmus at a significantly greater level compared with standard needle irrigation. The results of the present study revealed that laser-activated irrigation with PIPS tip had a positive effect in removing dentinal debris from an artificial groove created in the apical third of the root canals, and this result is harmonious with those of aforementioned studies.

Bubbles, the formation of an empty space in a liquid, are the basis of cavitation. Er:YAG laser irradiation is highly absorbed by hydroxyapatite and water (Paghdiiwala 1991, Armengol et al. 1999). When Er: YAG laser irradiation is absorbed by water, the energy causes evaporation (Brugnera et al. 2003, Kivanc et al. 2008). The vapour bubble starts to expand and form a void in front of the laser light. Matsumoto et al. (2011) demonstrated that the bubble increased in size and reached up to 1800 µm in 220 microseconds when a 300 µm laser tip was used, as in the present study. They stated that when the laser tip was inserted 2 and 5 mm short of the bottom of an artificial glass root canal model, the second cavitation bubbles were clearly observed at the bottom of the artificial root canal. Therefore, they suggested that it is not always necessary to insert the laser tip up to the terminus of the canal, because the cavitation bubbles also assist in cleaning the apical region. In the present study, this finding has been confirmed. The PIPS optic tip was inserted only in the coronal part of the root canals, and the apically placed dentinal debris was effectively removed.

Photon-induced photoacoustic streaming tips have been used at subablative levels with specific models and settings and with a radial and stripped tip of novel design. This technique uses low energy levels and short microsecond pulse rates (50 µs) to generate peak power spikes. The profound photoacoustic shock wave it induces facilitates three-dimensional movement of the irrigation solutions (DiVito & Lloyd 2012a). Previous studies have shown that the use of erbium lasers in the root canal may result in side effects. Matsuoka et al. (2005) observed carbonization and cracks on the root canal walls when the laser tips were used for root canal preparation. Kimura et al. (2002) monitored a temperature increase of up to 6 °C. The subablative parameters in the PIPS technique result in a photomechanical effect, which occurs when the light energy is pulsed in a fluid, rather than a thermal effect (Peters et al. 2011, DiVito et al. 2012b).

The traditional laser applications necessitate conventional preparation for at least up to size 30 and the laser tip need to reach apical third of the root. However, the PIPS tip does not need to reach the canal terminus, and it is placed into the coronal reservoir only of the root canal. Therefore, this technique allows for minimally invasive preparation of the root canal (DiVito & Lloyd 2012a, DiVito et al. 2012b). The effect may be explained by the increased NaOCl reaction kinetics with laser activation (de Groot et al. 2009, Macedo et al. 2010).

Both PIPS and ultrasonic irrigation techniques are based upon the transmission of acoustic energy to an irrigant in the root canal space (Ahmad et al. 1987, DiVito et al. 2012b). The acoustic streaming effect of the irrigant in the ultrasonic has been shown to be more effective than syringe irrigation in
removing artificially created dentine debris placed in simulated uninstrumented extensions and irregularities in root canals (Lee et al. 2004). In a recent study, De Moor et al. (2010) evaluated the efficacy of laser-activated irrigation with erbium lasers and passive ultrasonic irrigation in terms of removing artificially placed dentine debris in root canals. They showed that the application of the laser-activated irrigation technique for 20 s was as efficient as passive ultrasonic irrigation for 3 × 20 s. Similarly, de Groot et al. (2009) revealed that laser-activated irrigation was significantly more effective in removing dentine debris from the apical part of the root canal than passive ultrasonic irrigation when the irrigant was activated for 20 s. In the present study, laser-activated irrigation with PIPS tip removed more dentinal debris than ultrasonic irrigation. This result can be explained by the high amounts of energy being transferred to the irrigant with laser activation compared with passive ultrasonic irrigation (de Groot et al. 2009).

**Conclusion**

Photon-induced photoacoustic streaming technique was significantly more effective than both sonic and ultrasonic irrigation in removing apically placed dentinal debris.

**References**


