SEM analysis of the laser activation of final irrigants for smear layer removal

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Fig. 1

Fig. 2

Fig. 1_Access opening.
Fig. 2_Stainless steel #10. K-file for patency.

_Introduction

The complete restoration of the root canal space with an inert filling material and the creation of a fluid tight seal are the goals of successful endodontic therapy.[1] In order to create a fluid tight seal, it is imperative that the endodontic filling material closely adapts or bonds to the tooth structure. This, however, is impaired by the presence of a smear layer, which invariably forms after endodontic instrumentation.[2,3] The smear layer contains organic material, odontoblastic processes, bacteria and blood cells.

Various materials and techniques have been reported with wide variations in their efficacy regarding the removal of the intra-canal smear layer.[2,4] The most widely used chemical for the purpose is EDTA, used in different formulations.[5] They have been reported to consistently produce canals with patent dentinal tubules.[6] However, it has been found to be less efficient in narrow portions of the canal[7], it requires a long application time for optimum results[8] and can seriously damage the dentin, if used in excess.[9]

Clinically, endodontic procedures use both mechanical instrumentation and chemical irrigants in the attempt to three dimensionally debride, clean and decontaminate the endodontic system.[10,11]

Even after doing this meticulously, we still fall short of successfully removing all of the infective microorganisms and debris. This is because of the complex root canal anatomy and the inability of common irrigants to penetrate into the lateral canals and the apical ramifications. It seems, therefore, appropriate to search for new materials, techniques and technologies that can improve the cleaning and decontamination of these anatomical areas.[12]

Some of these mechanically activated irrigation techniques include manual irrigation with needles, K-file, Master cone GP points, Irrisafe, ultrasonics, Endo-activator, Rotobrush, Roekobrush, etc. The newest of the lot is PIPS, i.e Photon-Induced Photoacoustic Streaming via laser. Hence it was chosen for the study.

_Material and methods

Forty single-rooted, extracted human teeth were used in the study. Teeth with fractures, cracks or any other defects were excluded. Subsequently, they were scaled with ultrasonics for the removal of calculus or any soft-tissue debris, washed with distilled water and then stored in normal saline. Standard endodontic access cavity preparations were performed and then a stainless-steel #10

K-file (Mani K-File) was inserted into the canal until the tip was just visible at the apical foramen to check for patency. Chemo-mechanical preparation was done up to F3 using rotary protapers (DENTSPLY Maillefer) along with EDTA gel (Glyde – DENTSPLY Maillefer) for all the samples.

Irrigation of all the samples during preparation was accomplished using 5 ml of 5.25% sodium hypochlorite between each file. Samples were then divided randomly into two groups, depending upon the method of activation of the final irrigant used.

These groups were further divided into two subgroups, depending upon the final irrigant used (Tab. 1):

_Subgroup A: 5.25% NaOCl (n = 10)
_Subgroup B: 17% EDTA (n = 10)

Activation of the irrigant for group I was done mechanically by agitating a stainless steel #25 K-file (2% taper) in the canal when it was filled with the final irrigant solution.

An Er:YAG laser with a wavelength of 2,940 nm (Fotona) was used to irradiate the root canals in Group II with a newly designed 12 mm long, 400 µm quartz tip. The tip was tapered and had 3 mm of the polyamide sheath stripped away from its end. The laser operating parameters used for all the samples (using the free-running emission mode) were as follows: 40 mJ per pulse, 20 Hz, at very short pulse (MSP) mode, which provides the same 400 W of peak pulse power as the parameters recommended by Olivi (20 mJ, 15 Hz, SSP). The coaxial water spray feature of the handpiece was set to 'off' while air settings were kept at 2. The tip was placed into the coronal access opening of the chamber just above the orifice, and was kept stationary. During the laser irradiation cycles, the root canals were continuously irrigated with the final irrigant to maintain hydration levels using a hand syringe with a 25 gauge needle positioned above the laser tip in the coronal aspect of the access opening, according to the above protocol.

GROUPS / SUB-GROUPS	GROUP I (Hand Activation)	GROUP II (Er:YAG with PIPS)
Sub Group A (5.25 % NaOCl)	n = 10	n = 10
Sub Group B (17 % EDTA)	n = 10	n = 10

Table 1_Subgroups depending on the final irrigant used.

After preparation, the root canal walls were dried using paper points. Longitudinal grooves were made on the distal and mesial root surfaces, preserving the inner shelf of the dentin surrounding the canal. Roots were then sectioned with the help of a chisel and mallet. Samples were then subjected to SEM to visualize the surface characteristics.

_Results

Group I specimens (hand activation) consistently exhibited a thick smear layer with NaOCl (subgroup A, Figs. 8a–c) while comparatively less smear layer was observed with EDTA (subgroup B, Figs. 9a–c). SEM examination demonstrated that when NaOCl irrigation was applied, a noticeable smear layer and occluded dentinal tubules remained on the treated surface. Debris, defined as dentin chips and pulp remnants loosely attached to the internal surface of the root canals, was present in the specimens in subgroup A (Group I). In the specimens of EDTA, mostly open dentinal tubules were observed in the coronal and the middle third while in the apical third of all specimens occluded tubules were observed.

Figs. 3 and 4_Chemo-mechanical preparation up to F3.
Fig. 5_Group I—Hand activation using stainless steel #25 K-file (n = 20).

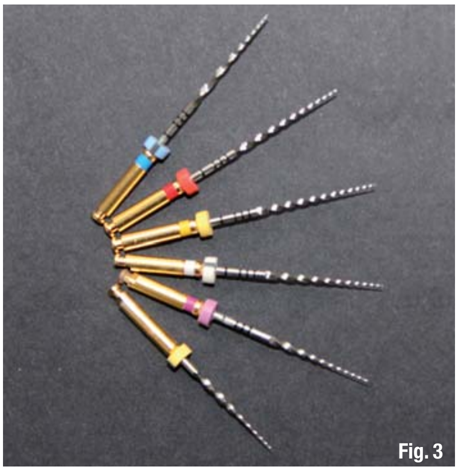


Fig. 3

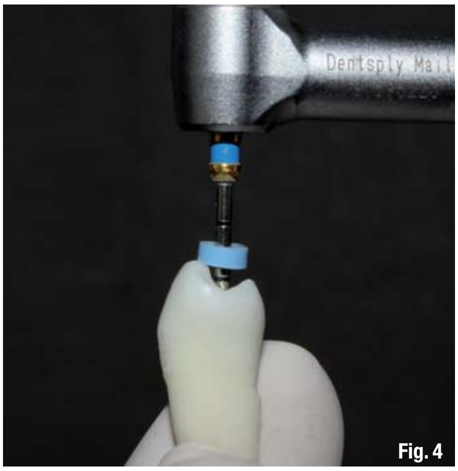


Fig. 4

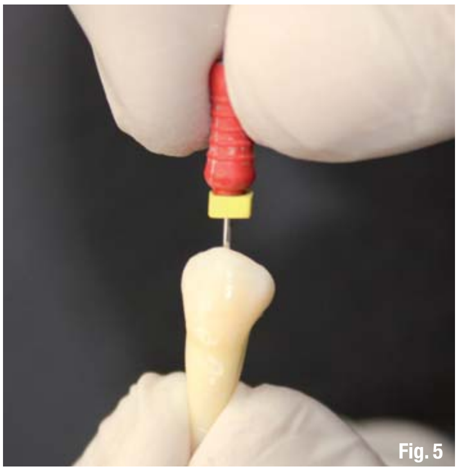


Fig. 5

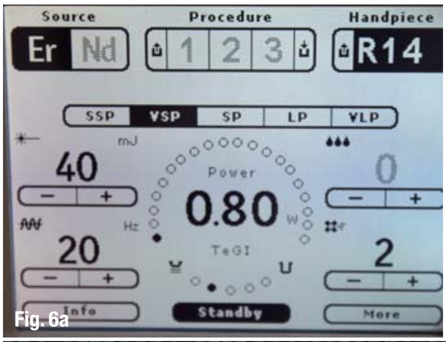


Fig. 6a

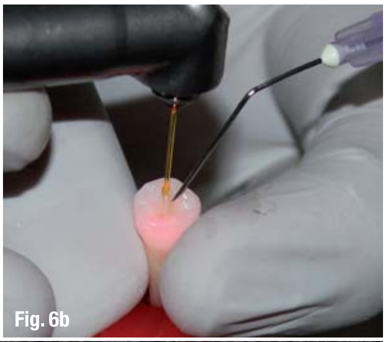


Fig. 6b


Fig. 7

Figs. 6a & b and 7_Group II—Er:YAG activation using Photon-Induced Photoacoustic Streaming tip (n = 20).

Group II specimens treated with the Er:YAG laser with PIPS showed the most effective removal of the smear layer from the root canal walls compared to Group I (hand activation) specimens. At higher magnifications (1,000x–2,000x) subgroup B (17 % EDTA) showed better results with exposed and intact collagen fibers and open dentinal tubules, even in the apical third (Figs. 11a–c), when compared with subgroup A (5.25 % NaOCl), where open dentinal tubules along with scattered dentinal chips were observed (Figs. 10a–c). None of the SEM images indicated signs of dentin melting.

_Discussion

Current instrumentation techniques using rotary instruments and chemical irrigation still fall short of successfully removing the smear layer from inside the root canal system. Mechanical activation of the chemical irrigant plays an important role in removing the smear layer. Fiber-guided lasers have also been used hoping to achieve some degree of success, however, there is limited availability of literature regarding this topic.

The concept of laser-activated irrigation is based on cavitation. Because of the high absorption of water by the mid-infrared wavelength of lasers, the cavitation process generates vapor-containing bubbles, which explode and implode in a liquid environment.[13] This subsequently initiates pressure/shock waves by inducing shear force on the dentinal wall. In a water-filled root canal, the shock waves could potentially detach the smear layer and disrupt bacterial biofilms. To efficiently activate irrigant and generate shock waves in the root canal, lasers with wavelengths from 940–2,940 nm have been used.[14–22]

5.25 % sodium hypochlorite was used in Group I because the majority of practitioners still use only sodium hypochlorite as the irrigant along with hand instruments. Hence sodium hypochlorite was used in Group I. To remove inorganic debris of the smear layer, use of aqueous EDTA had been recommended. But prolonged use of EDTA can cause dentinal erosion of the root canal by decalcifying the peritubular dentin. The recommended time in endodontic literature is only 1–2 minutes. Hence, 17 % aqueous EDTA was used for one minute in Group II to minimise time and damage.

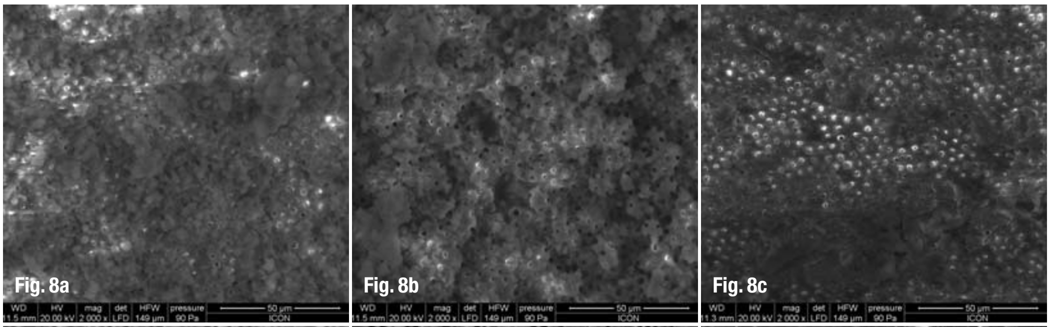


Fig. 8a Fig. 8b Fig. 8c

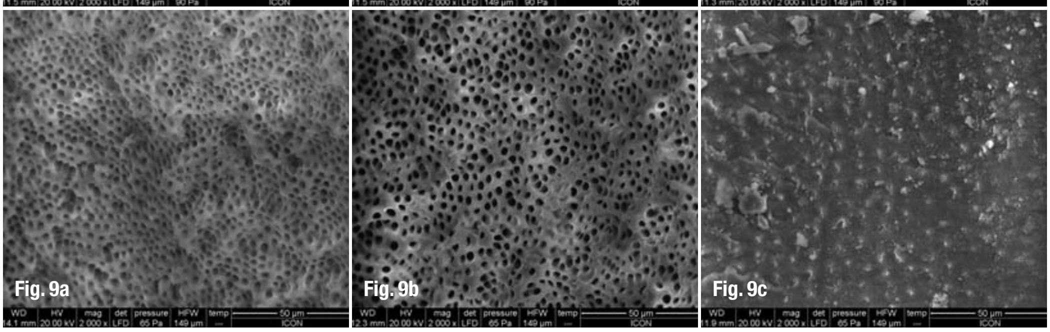


Fig. 9a Fig. 9b Fig. 9c

Fig. 8_Group I—Hand Activation (5.25 % NaOCl—Subgroup A): coronal third **(a)**, middle third **(b)**, apical third **(c)**.
Fig. 9_Group I—Hand Activation (17 % EDTA—Subgroup B): coronal third **(a)**, middle third **(b)**, apical third **(c)**.

The results of this study indicate that NaOCl subgroups could remove the smear layer in the coronal third; however, it did not remove the smear layer from the middle and apical third of the canal wall. EDTA is efficient in removing the smear layer, which is evident in this study for both groups. The effects of EDTA were limited to the coronal and middle third in Group I (hand activation) while it was effective even in the apical third for Group II (Er:YAG-PIPS). Ciucchi et al. stated that there was a definite decline in the efficiency of irrigating solutions along the apical part of the canals.[23] This can probably be explained by the fact that dentin in the apical third is much more sclerosed and there are fewer dentinal tubules present there.[24] Also apical reach, canal configuration, and smooth transition are a few of the anatomical key factors. Hence root canal success is dependent on apical third anatomy.

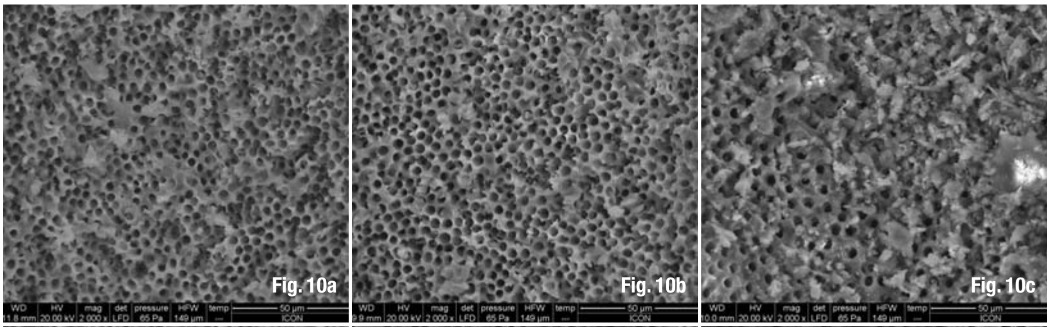
The Er:YAG laser used in this investigation proved to be more effective than the conventional technique in removing the smear layer. This finding can be attributed to the photomechanical effect seen when light energy is pulsed in liquid.[25-27] When activated in a limited volume of fluid, the high absorption of the Er:YAG wavelength in water, combined with the high peak power derived from the short pulse duration that was used for five seconds (three cycles), resulted in a photomechanical phenomenon. A profound "shockwave-like" effect is observed when a radial and stripped tip is submerged in a coronal chamber above the orifice. As a result of the very small volume, this effect may remove the smear layer and residual tissue tags and potentially decrease the bacterial load within the tubules and lateral canals.[28-30] By using lower sub-ablative energy (40 mJ) and restricting the placement of the tip to within the coronal portion of the tooth only, the undesired effects of the thermal energy, as previously described in the literature, was avoided.[31-45] In the current study, the smear layer and debris were not removed by thermal vaporisation, but probably by photomechanical streaming of the liquids, which were laser activated in the coronal part of the tooth.

Giovani Olivi and Enrico DiVito have described this light energy phenomenon as photon-induced photoacoustic streaming (PIPS). The effect of irradiation with the Er:YAG laser equipped with a tip of novel design at sub-ablative power settings (20 mJ, 15 Hz, SSP, 400 W peak power) is synergistically enhanced by the presence of EDTA. This leads to a significantly better debridement of the root canal, contributing to an improvement in treatment efficacy. Hence, the PIPS technique resulted in pronounced smear layer removal when used together with EDTA and at the settings outlined.

_Conclusion

Within the limitations of this study, the Er:YAG laser with PIPS showed significantly better smear layer removal than the hand-activation group. At the energy levels and with the operating parameters used, no thermal effects or damage to the dentin surface was observed. With the described settings, the Er:YAG laser produced a photomechanical effect, demonstrating its potential as an improved alternative method for debriding the root canal system in a minimally invasive manner._

Editorial note: A list of references is available from the publisher.



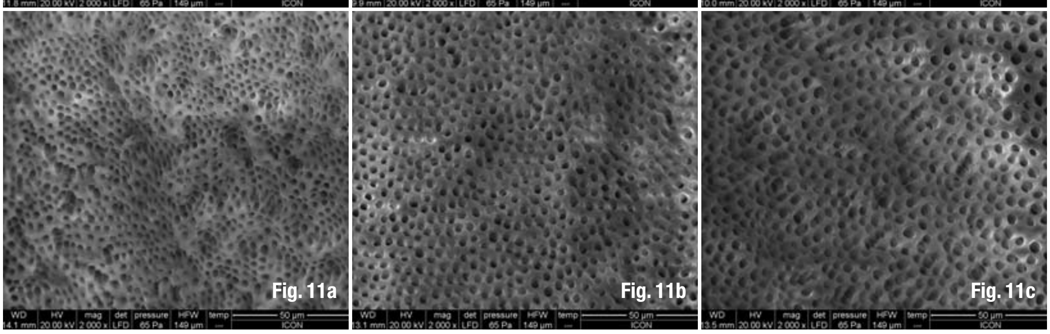


Fig. 10_Group II—Er:YAG with PIPS (5.25 % NaOCl—Subgroup A): coronal third **(a)**, middle third **(b)**, apical third **(c)**.

Fig. 11_Group II—Er:YAG with PIPS (17 % EDTA—Subgroup B): coronal third **(a)**, middle third **(b)**, apical third **(c)**.

_contact roots

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