Journal of Lasers in Medical Sciences

J Lasers Med Sci 2021;12:e22

Original Article

http://journals.sbmu.ac.ir/jlms

doi 10.34172/jlms.2021.22

A Comparative Evaluation of Smear Layer Removal Using Erbium:YAG Laser-Activated Irrigation, Sonic Irrigation, and Manual Dynamic Irrigation: A Scanning Electron Microscope Study

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Received: 14 October 2020
Accepted: 12 December 2020
epublished: 9 June 2021

Abstract

Introduction: The conventional chemomechanical procedures are ineffective in complete disinfection of the pulp space due to the complexities of the root canal architecture. The present study aims to compare the efficacy of erbium: YAG laser-activated irrigation, sonic irrigation, and manual dynamic irrigation in the removal of the smear layer through a scanning electron microscope study.

Methods: Fifty extracted single rooted mandibular premolars with single canal were used and instrumented until F3 ProTaper rotary file reached the working length. Upon the completion of the canal preparation, each specimen was irrigated with 3 mL of 4% NaOCl for 3 minutes, 3 mL saline for 1 minute and 3 mL of 17% EDTA for 3 minutes. The teeth were assigned to three experimental groups (n=15 each): manual dynamic irrigation, sonic irrigation (EndoActivator), and Er:YAG laser using an X pulse tip. Root canals were sectioned longitudinally and the smear layer at the apical, middle and coronal third was examined under a scanning electron microscope. Smear layer scores were analyzed by Kruskal-Wallis and Mann-Whitney U tests at $P=0.05$.

Results: The Er:YAG laser group showed significantly lower smear layer scores in the apical third as compared to all other groups. EndoActivator resulted in better cleaning efficacy at the apical area compared to manual dynamic agitation.

Conclusion: This study showed results in favor of Er:YAG with an X-pulse tip followed by EndoActivator activation.

Keywords: Smear layer; Erbium:YAG laser-activated irrigation; Sonic irrigation; Manual dynamic agitation

Introduction

The smear layer on the surface of the prepared root canal is composed of dentinal shavings and soft tissue debris and may harbor residual bacteria.[1] It should be removed before canal obturation to improve the adhesion and penetration of endodontic sealers which would result in a superior seal.[2] To achieve these objectives, there must be an efficient irrigation technique which allows adequate delivery and flow of irrigant, especially at the apical third, to effectively debride the canal system, but to avoid periapical extrusion.[3]

During endodontic therapy, irrigation with 5.25% sodium hypochlorite kills microbes and dissolves the organic constituent, whereas ethylenediaminetetraacetic acid (EDTA) removes the inorganic portion of the smear layer.[4]

The conventional needle irrigation technique is unable to clean the pulp space due to the complexities of the canal system. Also, the vapor lock effect inhibits the exchange of irrigants in the apical third and prevents smear layer removal from the canal system.[3] Several techniques have been introduced to enhance the effectiveness of irrigants.

The Er:YAG laser has been approved by the FDA to be used in endodontics and has been shown to be efficient in the removal of the smear layer.[5]

In addition to customary chemo-mechanical protocols, laser systems have been proposed to enhance debridement and disinfection.[6-8] The combined effect of photoablation and photoacoustic streaming in lasers results in smear layer removal.[9] The present research aimed to compare the effectiveness of manual agitation, EndoActivator and the Er:YAG laser with an X-Pulse tip on the removal of the smear layer. The null hypothesis to be tested was that the efficacy of smear layer removal was not influenced by different experimental agitation systems.

Please cite this article as follows: Thapak G, Arya A, Grewal MS, Arora A. A comparative evaluation of smear layer removal using erbium:yag laser-activated irrigation, sonic irrigation, and manual dynamic irrigation: a scanning electron microscope study. *J Lasers Med Sci.* 2021;12:e22. doi:10.34172/jlms.2021.22

Material and Methods

Fifty extracted single-rooted premolar teeth with a single canal were used in this study. The teeth with extensive restorations, root caries, fractures, internal or external resorption, immature apexes and dilacerated roots were excluded from the study.

Sample Preparation

Conventional access opening was done and the canal negotiated with a #15K file until it appeared at the apical terminus and working length was established 0.5mm short of this measurement. The apices of all teeth were sealed with utility wax to simulate the clinical situation.

The glide path was prepared with a #10 K file and the root canals of all the teeth were instrumented using ProTaper Universal rotary files (Dentsply) following the manufacturer's recommendations until ProTaper F3 file reached the working length. During instrumentation, irrigation was done with 3ml of 4% NaOCl (Merck Specialities, Mumbai) and recapitulation was done after each instrument used in the canal by inserting a small size file to the working length.

Final Irrigation Protocol

Upon the completion of the canal preparation, each specimen was irrigated with 3ml of 4% NaOCl for 3 minutes, 3 mL saline for 1 minute, and 3 mL of 17% EDTA for 3 minutes.

The irrigant was delivered by means of a side vented needle -30 gauge (Canal clean, Biodent Co. Ltd) inserted passively 2mm short of working length with back and forth motion of 2-3 mm. Based on the mode of irrigant activation, the samples were randomly assigned to the following groups (n = 15).

- Control group: n = 5 (no activation done): After irrigation, the samples were left undisturbed without subjecting the irrigant to intracanal agitation.
- Group 1: n = 15 (Gutta Percha, Mani Inc, Belgium): Irrigant agitation was done with a well-fitting Gutta Percha Master cone for 1 minute per canal at a frequency of 100 push-pull motions/minute.
- Group 2: n = 15 (Endoactivator, Dentsply): The EndoActivator system was used according to the manufacturer's recommendations. Irrigant activation was done for 1 minute with a 25/04 noncutting polymer tip of the EndoActivator placed 1 mm short of working length at 10,000 cycles per minute.
- Group 3: n = 15 (Er:YAG Laser with an X-Pulse Tip, Fidelis; Fotona): A 2940 nm wavelength Er:YAG laser (Fotona, AT Fidelis, Ljubljana; the laser was used with the following parameters: 20 mJ of energy per pulse at 15 Hz frequency, pulse length of 50 µs for 40 seconds with energy density of 15.92 J/cm^2 per pulse and average power of 0.3 W. The X-pulse tip was kept stationary at the level of the canal orifice and the water spray feature was set in an 'off' mode.

Examination of Smear Layer Removal

The specimens were then longitudinally sectioned using a serrated laboratory disk (Brasseler, Savannah, GA) and split into two halves. These halves were fixed in 2% glutaraldehyde and dehydrated with ethyl alcohol 30%, 50%, 70%, 80%, 90%, and 100% respectively for 10 minutes each. The dried specimens were mounted on metal stubs, placed in vacuum chamber and after gold sputtering, they were examined under a scanning electron microscope (LEO Evo 40X VP; Carl Zeiss AG, Oberkochen, Germany

The photomicrographs (4000X) of the dentinal wall on each of the coronal, middle and apical thirds were made for smear layer evaluation. The scoring of the smear layer was done according to the criteria given by Hulsmann et al.[4]

Score 1 – complete absence of a smear layer; open dentinal tubuli.

Score 2 – Presence of a slight smear layer; most dentinal tubules open.

Score 3 – Presence of a homogeneous smear layer covering the canal wall; a few dentinal tubules open

Score 4 – A thick smear layer covering the complete canal wall; no open dentinal tubules

Score 5 – An entire canal wall covered by a heavy smear layer.

Results

The chi-square test for smear layer scores confirmed significant differences in the apical third between the Control, Manual Agitation, EndoActivator and X-Pulse tip groups. Scores 2 and 3 were significantly more among the EndoActivator and X-pulse tip groups and scores 4 and 5 were significantly more among the control and manual agitation groups.

At the middle third, scores 2 and 3 were significantly more among the EndoActivator and X-pulse tip groups, whereas score 4 was significantly more among the control and manual agitation groups.

At the coronal third, scores 1 and 2 were significantly more among the EndoActivator and X-pulse tip groups and score 4 was significantly more among the control group (Figure 1).

The inter-group comparison of mean smear layer removal at the apical, middle and coronal thirds was done using the Mann-Whitney U test. At the apical third, the mean smear layer score was significantly more among the control group and the manual agitation group than the EndoActivator group and the X-Pulse tip group (Table 1). At the middle third, the mean smear layer score was significantly more among the control and manual agitation groups than the EndoActivator group which was significantly more than the X-Pulse tip group (Table 2). At the coronal third, the mean smear layer score

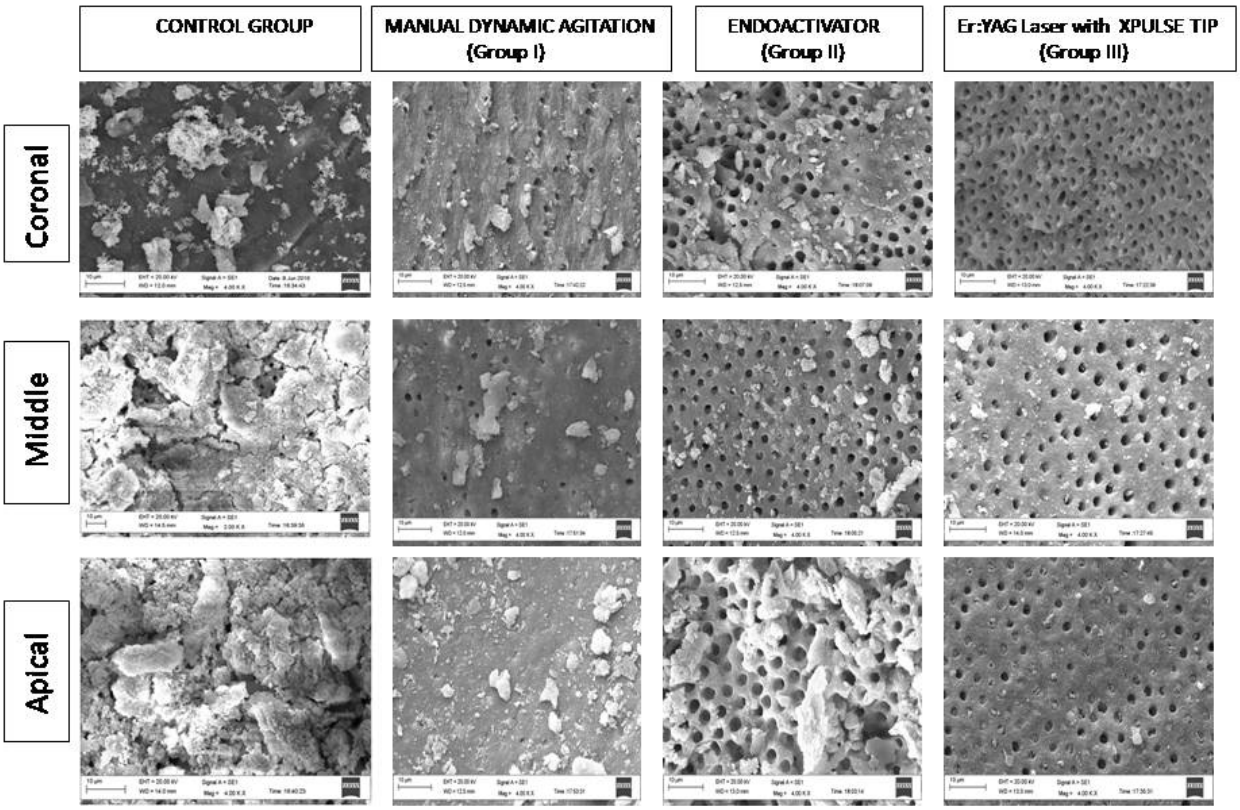

Figure 1. SEM Photomicrographs of All the Groups at Coronal, Middle and Apical Third.

was significantly more among the control and manual agitation groups than the EndoActivator and X-Pulse tip groups (Table 3).

The inter-group comparison of the mean smear layer score was done using the Wilcoxon signed-rank test. The mean smear layer score was significantly more at the apical third in comparison to the middle third which was more than the coronal third.

Discussion

For successful endodontic treatment, all debris, bacterial toxins and necrotic tissues should be removed completely; hence, irrigation forms an essential aspect for efficient debridement of canal space with complex internal anatomy and irregularities that cannot be contacted by instrumentation.[10]

Studies have concluded that the apical portion of the root canal is the most critical due to anatomic intricacies within the apical third.[11] Khademi et al suggested that shaping the canal with file #30 with a 0.06% coronal taper is sufficient for proper irrigant penetration at the apical third.[12] Based on these studies, the canals were instrumented with ProTaper rotary files (Dentsply Mallifer, USA) until Protaper F3 file reached the working length to achieve a suitable coronal taper and apical preparation corresponding to the #30 file. A closed apical system was used to reproduce clinical conditions to

Table 1. The Inter-group Comparison of Mean Smear Layer Removal at Apical Third

		Apical	
		Mean Difference	*P* Value[a]
Control Group	Manual Agitation	0.50	0.046*
Control Group	EndoActivator	0.80	0.030*
Control Group	X-Pulse tip	1.13	0.001*
Manual Agitation	EndoActivator	0.30	0.060
Manual Agitation	X-Pulse tip	0.63	0.040*
EndoActivator	X-Pulse tip	0.33	0.078

[a] Mann-Whitney U test; * Significant difference.

Table 2. The Inter-group Comparison of Mean Smear Layer Removal at Middle Third

		Middle	
		Mean Difference	*P* Value[a]
Control Group	Manual Agitation	0.43	0.038*
Control Group	EndoActivator	1.03	0.001*
Control Group	X-Pulse tip	1.63	<0.001*
Manual Agitation	EndoActivator	0.60	0.032*
Manual Agitation	X-Pulse tip	1.20	0.001*
EndoActivator	X-Pulse tip	0.60	0.042*

[a] Mann-Whitney U test; * Significant difference.

Table 3. The Inter-group Comparison of Mean Smear Layer Removal at Coronal Third

		Coronal	
		Mean Difference	***P* Value**[a]
Control Group	Manual Agitation	0.40	0.054
Control Group	EndoActivator	0.87	0.040*
Control Group	X-Pulse tip	1.47	0.001*
Manual Agitation	EndoActivator	0.47	0.048*
Manual Agitation	X-Pulse tip	1.07	0.001*
EndoActivator	X-Pulse tip	0.60	0.045*

[a] Mann-Whitney U test; * Significant difference.

simulate gas entrapment into the root canal.[13]

Tay et al demonstrated that a liquid film is created along the air bubble canal wall juncture due to the extrusion of irrigant beyond 1-1.5 mm of a side vented irrigation needle. This causes the presence of demineralized sclerotic intertubular dentin in the apical portion of the canal where failure to replace the irrigant leads to the accumulation of debris in this region. After the removal of the smear layer, chelating agents cause demineralization of the collagen matrix on the radicular dentinal wall. This porous interwining collagen fibrillar mesh can trap debris in the absence of strong turbulent fluid flow.[14]

This explains the highest mean smear layer score observed with the control group in our study, which is in accordance with the study conducted by Fraser who concluded that needle irrigation is inefficient in delivering irrigants at the apical third in a closed system.[15]

Manual dynamic agitation (MDA) is done with either well-fitted gutta-percha or a master apical file at 100 vibrations per minute, which allows the continuous flow of irrigants at the apical third and removes the smear layer. In our study, MDA performed significantly better than the control group at the middle and apical thirds, which is in agreement with the study conducted by Andrabi et al.[16] This technique has several advantages such as being economical, being easily available, and no need for separate equipment.[16]

The EndoActivator works on a hydrodynamic phenomenon and the vibrating tip generates intracanal waves resulting in bubbles which expand and then collapse and implode. Each implosion produces up to 30 000 shockwaves which penetrate and break up biofilms present in the canal wall making it clean. The EndoActivator system effectively removes the smear layer, debrides the canals and disrupts biofilms within endodontic space.[17-21]

Concerning smear layer removal, the EndoActivator provided significantly better results as compared to control and manual activation, which is in accordance with previous studies conducted by Blank-Goncalves et el[22] and de Gregorio et al.[23] The coronal and middle thirds showed significantly better cleanliness in comparison to the apical third, which might be due to the restrained displacement amplitude of the EndoActivator in the apical root canal. This resulted in decreased agitation energy and hence less elimination of the smear layer, which is in agreement with the study conducted by Uroz-torres.[24]

Laser-activated irrigation has been proposed to enhance the effect of irrigants in removing the smear layer as they facilitate deeper penetration of irrigant into dentinal tubules and apical areas.

Laser-activated irrigation works on the cavitation principle. Laser energy results in formation of vapour bubbles in the irrigant solution, which expand in volume and then implode. The shear forces and the shockwaves generated from collapsing bubbles augments the removal of smear layer from dentinal walls thereby increasing the efficiency of the irrigant solution.[25-29]

Divito, in 2010, introduced the photon-initiated photoacoustic streaming (PIPS) tip with tapered radial design and 3 mm of polyamide sheath stripped from its distal end which enhances the lateral diffusion and propagation of photoacoustic waves in the irrigant solution.[30] PIPS results in better dislodgement of debris and the inorganic smear layer with minimal damage to the dentinal structure.[31] Similar results were shown by Olivi.[32]

In comparison to the PIPS tip, the newly designed X-Pulse tip is cylindrical in shape with a conical end without a cleavage, 400 µm in diameter, and 14 mm in length and has the advantage of being cost-effective as compared to the PIPS tip. Studies have demonstrated that the Er:YAG laser when used at sub-ablative specifications (average power of 0.3 W, 20 mJ at 15 Hz) in combination with EDTA is more efficient than conventional approaches for smear layer debridement.[4] A study conducted to evaluate the cleaning efficacy of PIPS tips 400/14 & 600/9 versus the X Pulse tips 400/14 & 600/14 demonstrated comparable results.[31] The results of our study revealed that the group treated with the Er:YAG laser with the X-Pulse tip showed significantly better smear layer removal along the dentinal canal walls as compared to other groups. The SEM image of the root canal revealed optimal cleaning with less damage to dentinal tubules, root canal walls and hydroxyapatite crystals. Placement of the tip at the coronal orifice prevents undesirable effects of thermal energy.[4]

In the group treated with the Er:YAG laser and the X-Pulse tip, the smear layer score was significantly less in coronal than the middle third which in turn was distinctly cleaner than the apical portion. This may be ascribed to the fact that due to the conical shape of the canal, coronal dentin is exposed to a higher volume of irrigants leading to a better flow of irrigants in comparison to apical dentin. These results are consistent with the previous findings by Guidotti et al[33] and De Groot.[34]

Despite the fact that irrigant activation devices were used, the coronal third was cleaner than the apical third and the same findings were observed in many previous researches. This can be co-related to the larger diameter of the root canal system at the coronal third when compared to the apical third, exposing a higher volume and better flow of irrigant in the coronal third leading to better smear layer removal efficacy.[20,21]

The limitation of this in vitro study is that the teeth selected had straight canals; hence, there is a scope for future research on the efficacy of the irrigant activation system in root canal debridement in curved canals.

Conclusion

This study showed results in favor of Er:YAG with the X-pulse tip followed by EndoActivator activation. Regardless of the technique of the irrigant activation, the coronal dentinal canal walls were substantially cleaner as compared to the apical canal. Complete removal of the smear layer was not achieved with any of the irrigation activation techniques investigated in our study. Further in vivo research is necessary to evaluate the effect of laser activation in endodontics. There is a need to ascertain, from a clinical viewpoint, how these devices are apprehended in terms of their feasibility and ease of operation.

Conflict of Interests

The authors declare that they have no conflict of interest.

Acknowledgement

We would like to thank Dr. Ruchita Pal, the in-charge of the Scanning Electron Microscopy department at Jawaharlal Nehru University, New Delhi, without whom the study would have not been possible.

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