Comparison of Smear Layer Removal Ability of QMix with Different Activation Techniques

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Abstract

Introduction: To evaluate the effectiveness of QMix solution (Dentsply Tulsa Dental Specialties, Tulsa, OK) on the smear layer using the following irrigation activation techniques: the EndoActivator (EA) system (Dentsply Tulsa Dental Specialties), photon-initiated photoacoustic streaming (PIPS), and an Er:YAG laser with an endodontic fiber tip. **Methods:** Sixty-four extracted single-rooted human teeth were decoronated and the canals instrumented with ProTaper (Denstply Maillefer, Ballagues, Switzerland) up to size F4. The canals were irrigated with 5.25% sodium hypochlorite and a saline solution for 1 minute each. The specimens were then divided randomly into 4 experimental and 4 control groups ($n = 8$) according to the final irrigation activation technique. These groups included group 1, 2.5 mL QMix; group 2, QMix + EA; group 3, QMix + PIPS; and group 4: QMix + Er:YAG. Laser activated distilled water was used as control groups 5, 6, 7, and 8. Teeth were split longitudinally, and specimens were observed under a scanning electron microscope. Images were taken at the coronal, middle, and apical thirds of the teeth at a magnification of 1000× and were scored in the presence of the smear layer. Data were analyzed with Kruskal-Wallis and Mann-Whitney *U* tests. **Results:** The highest scores were found in the apical third of all groups ($P < .05$). The QMix + Er:YAG group removed the smear layer more effectively than the nonactivated QMix group in the apical third ($P < .05$). The QMix + EA group removed the smear layer significantly in all thirds of the teeth when compared with the nonactivated QMix group ($P < .05$). The QMix + PIPS group showed a significantly better effect than the QMix group in the coronal third ($P < .05$). **Conclusions:** The EA and Er:YAG laser enhanced the smear layer removal ability of QMix in the apical thirds of the canals. QMix removed more smear layer in the coronal thirds when activated with the PIPS technique. *(J Endod 2016;42:1279–1285)*

Key Words

EndoActivator, Er:YAG laser, photon-initiated photoacoustic streaming, QMix, smear layer

Significance

Irrigants are essential for successful debridement of the root canals, but no single solution has been shown to be capable of removing both organic and inorganic parts of the smear layer. QMix is a novel endodontic irrigant containing EDTA, chlorhexidine, and a nonspecified detergent. Laser-activated irrigation has been introduced to supplement conventional endodontic cleaning procedures. This study examined QMix solution with activation methods especially laser techniques.

The presence of a smear layer acts as a physical barrier and prevents the penetration of root canal irrigants, medications, sealers, and root canal filling materials into dentinal tubules (1, 2). Moreover, it is a nutrient for bacteria in dentinal tubules. Therefore, the removal of the smear layer is recommended for disinfection and 3-dimensional obturation of the root canal system (3).

Irrigants are essential for successful debridement of the root canals with mechanical procedures (4). There is no single solution that has been shown to be capable of removing both organic and inorganic parts of the smear layer. The use of sodium hypochlorite (NaOCl, 0.5%–5.25%) and EDTA (15%–17%) has been reported to be effective in removing organic and inorganic components of the smear layer (5). QMix 2in1 Irrigating Solution (Dentsply Tulsa Dental Specialties, Tulsa, OK) is a novel endodontic irrigant containing EDTA, chlorhexidine gluconate, and a nonspecified detergent that has been shown to be as effective as 17% EDTA in removing the smear layer (6). Stojicic et al (7) showed that there was no significant difference between QMix and EDTA solutions for smear layer removal, and they stressed that when QMix is used, there are more open dentinal tubules after smear layer removal. In addition, QMix solution is as effective as NaOCl and chlorhexidine solutions at killing microorganisms.

Traditionally, irrigation is performed using a needle and syringe in conventional syringe irrigation (CSI), but CSI-transmitted solutions go no more than 0–1.1 mm beyond the needle tip (8). It has been shown that large amounts of debris remain in root canal irregularities after the use of CSI (9, 10). Therefore, the penetration depth of the irrigant and its antimicrobial capacity are limited (11).

However, the root canal system often has a very complex anatomy with lateral canals, isthmuses, complex branching, and deltas that make complete debridement and disinfection impossible (12). Additionally, because of the vapor lock that results in trapped air in the apical third of the root canals, the effectiveness of irrigating solutions

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0099-2399/$ - see front matter

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http://dx.doi.org/10.1016/j.joen.2016.04.022

remains limited in the apical one third (13, 14). Thus, irrigant activation is suggested to increase the efficacy of irrigant delivery and improve root canal cleanliness (15–18).

The EndoActivator (EA) system (Dentsply Tulsa Dental Specialties), a sonically driven irrigant activation system, contains a portable handpiece and disposable flexible nondentin cutting polymer tips of 3 different sizes. The system produces a vigorous intracanal fluid agitation, and mechanical swinging is produced mainly at the tip of the activator with a frequency ranging from 1 to 10 kHz (13).

A laser-activated irrigation treatment with an erbium laser (Er:YAG with a wavelength of 2,940 nm) has been presented as an activation method of irrigation solution. An Er:YAG laser has the highest absorption in water and a high affinity for hydroxyapatite, and it provides effective removal of the debris and smear layer from the complex root canal systems. The effect is based on explosive vapor bubbles with a secondary cavitation effect by the pulsed energy transferred to solutions (18–21).

Recently, a photoacoustic technique called photon-induced photoacoustic streaming (PIPS), a light energy phenomenon, was reported to enable effective debris and smear layer removal with a newly designed radial and stripped tip or a 21-mm-long × 400-μm-diameter endodontic fiber (18, 19). In this technique, the Er:YAG laser is used at low energy levels (0.3 W) and short microsecond pulse rates (50 microseconds) to generate peak power spikes. Moreover, the profound photoacoustic shock wave allows for 3-dimensional movement of the irrigation solutions. Another distinguishing feature of this method is the ability to position the tip only at the pulp chamber without moving into the root apex (16).

The aim of this study was to evaluate the effectiveness of QMix solution on the smear layer using the following irrigation activation techniques: the EA, PIPS, and an Er:YAG laser with an endodontic fiber tip.

Materials and Methods

Sample Size Calculation

The sample size was determined using G*Power 3.0.10 software (v 3.0.10; Franz Faul, Kiel University, Kiel, Germany). A total of 8 teeth per group were chosen considering the following criteria: power = 0.80, α = 0.05, effect size = 0.686, and standard deviation of 0.9 for smear scores.

Selection and Preparation of the Samples

Sixty-four single-rooted human mandibular premolars extracted for periodontal and orthodontic reasons from patients aged 16–19 years were obtained from the Department of Oral and Facial Surgery with the approval of the Ethics in Research Committee of Bezmialem Vakif University, Istanbul, Turkey. All teeth were controlled with digital radiographs (DIGORA; Soredex, Helsinki, Finland) to ensure that there was a single root canal, no calcifications, and the absence of a complicated root canal anatomy. The selected teeth were cleaned of debris and soft tissue remnants mechanically and ultrasonically and stored in 10% formalin until use. Teeth were decoronated, and roots were standardized using a diamond disc operated at low speed to 16 mm in length. An ISO size #15 K-type file (Denstply Maillefer, Ballagues, Switzerland) was inserted into the root canal until just visible at the apical foramen. The working length (WL) of each root canal was then established 1 mm short of the apical foramen. To simulate the clinical situation, each apex was sealed with sticky wax.

The root canals were prepared with ProTaper rotary instruments (Dentsply Maillefer) up to apical size #40 (F4). A coronal reservoir for irrigant placement was created with a size 5 Gates Glidden drill placed 5 mm into the canal (22). The canals were irrigated with 2 mL 5.25% NaOCl between each file. During the irrigation procedures, a 27-G syringe needle (NaviTip; Ultradent, South Jordan, UT) was used, and the needle was placed 1 mm from the WL and then moved backward and forward.

At the end of instrumentation, 5 mL 5.25 % NaOCl for 1 minute and then 5 mL distilled water for 1 minute were used for the initial irrigation. Next, the specimens were divided randomly into 8 groups of 8 roots each according to the types of final irrigants and activation.

The experimental groups (n = 8) were as follows:

1. QMix + no activation (QMix + CSI)
2. QMix + EA activation (QMix + EA)
3. QMix + PIPS activation (QMix + PIPS)
4. QMix + Er:YAG laser with endodontic fiber tip activation (QMix + Er:YAG)

The negative control groups (n = 8) were as follows:

1. Distilled water + no activation (distilled water + CSI)
2. Distilled water + EA activation (distilled water + EA)
3. Distilled water + PIPS activation (distilled water + PIPS)
4. Distilled water + Er:YAG laser with endodontic fiber tip activation (distilled water + Er:YAG)

Final Irrigation Protocols

No-activation Group. A 2.5-mL QMix solution for the positive controls and 2.5 mL distilled water for the negative controls were flushed into the canal using a 27-G needle (NaviTip) for 90 seconds per canal. The needle was placed 1 mm short of the WL and then moved backward and forward. No additional activation of irrigants was performed.

The EA System Activation. The EA system was performed using a handpiece at 10,000/min cpm with a size 25/.04 (red) polymer tip. The tip was inserted 1 mm short of the WL.

Er:YAG Laser with Endodontic Fiber Tip Activation. Er:YAG laser activation was performed with a wavelength of 2940 nm (Fidelis; Fotona, Ljubljana, Slovenia) and an R14 handpiece with a 300-μm endodontic fiber tip (Preciso, Fotona). The water and air were turned off. The protocol had been set to 1 W, 20 Hz, and 50 mJ as specified by the manufacturer.

PIPS Activation. An Er:YAG laser with a wavelength of 2940 nm (Fidelis) was used with a 12-mm-long, 400-μm-diameter quartz tip (PIPS). PIPS was performed at 0.3 W, 15 Hz, and 20 mJ per pulse as specified by the manufacturer. The water and air were turned off. The tip was placed in the coronal reservoir.

The final irrigation/activation procedures resulted in 90 seconds of total irrigant delivery time. For the QMix and distilled water activated groups, a 2.5-mL solution was used. All samples were activated for 20 seconds with a resting time of 10 seconds after activation. The application was repeated 3 times. During the activation procedure, irrigation was gently continued through the root canal opening. After these procedures, each sample was immediately irrigated with 3 mL distilled water and dried with #4 ProTaper paper points.

Evaluation by Scanning Electron Microscopy

Parallel grooves were opened along the buccal and lingual surfaces with a diamond disc without water cooling and without touching the inner face. Then, the roots were split along the longitudinal axis in 2 halves, and both halves of the sections were dehydrated in the ascending alcohol series for 24 hours (70%–100%), sputter coated with gold, and then examined with a scanning electron microscope (LEO 440 Computer Controlled Digital; Leica Zeiss, Cologne, Germany). Scanning electron microscopic photomicrographs were taken at 1000× magnification at the coronal, middle, and apical thirds of the root canals, and the smear

TABLE 1. Means and Standard Deviation (SD) Score Values of the Smear Layer for Different Activation Techniques

	QMix (mean ± SD)	DW (mean ± SD)
Coronal		
No activation	1.50 ± 0.53^{a}	4.00 ± 0^{c}
EA	1.00 ± 0^{b}	4.00 ± 0^{c}
PIPS	1.00 ± 0^{b}	4.25 ± 0.46^{c}
Er:YAG	$1.38 \pm 0.52^{a,b}$	4.13 ± 0.35^{c}
Middle		
No activation	2.00 ± 0.76^{a}	4.00 ± 0^{c}
EA	1.25 ± 0.71^{b}	4.13 ± 0.35^{c}
PIPS	$1.5 \pm 0.53^{a,b}$	4.13 ± 0.35^{c}
Er:YAG	2.00 ± 0.53^{a}	4.75 ± 0.46^{c}
Apical		
No activation	4.00 ± 0.53^{a}	4.88 ± 0.35^{c}
EA	3.38 ± 0.52^{b}	4.75 ± 0.46^{c}
PIPS	$3.50 \pm 0.76^{a,b}$	4.25 ± 0.46^{c}
Er:YAG	3.38 ± 0.52^{b}	4.25 ± 0.46^{c}

EA, EndoActivator system; PIPS, photon-initiated photoacoustic streaming.
$P < .05$. Means with different superscript letters are statistically different within each third of the root according to the Mann-Whitney *U* test.

layer was scored according to Hülssman et al (23). Score 1 indicates no smear layer, and all dentin tubules are open and clean. Score 2 indicates a small amount of smear layer, and some dentin tubules are open. Score 3 indicates a homogenous smear layer covering the root canal wall, and only a few dentin tubules are open. Score 4 indicates a complete root canal wall covered by a homogenous smear layer, and no dentin tubules are open. Score 5 indicates a heavy, nonhomogenous smear layer covering the complete root canal wall. All samples were independently evaluated by 2 observers. If there were conflicting results between these observers, the lower score was chosen each time.

Statistical Analysis

Kolmogorov-Smirnov tests showed the data were not normally distributed; therefore, the differences between irrigation techniques were compared nonparametrically using Kruskal-Wallis and Mann-Whitney *U* tests, and the Friedman and Wilcoxon signed rank tests were used for comparison of smear scores within the groups of thirds. All statistical analyses were performed using IBM SPSS 20 software (IBM SPSS Inc, Chicago, IL). A significance level of .05 was used for all statistical tests.

Results

The result of the smear layer scores is presented in Table 1. The distribution of the QMix groups' smear layer scores are shown in Figure 1. All of the negative control groups (all activated and nonactivated distilled water) revealed a thick smear layer in all thirds (Fig. 2). These groups had a significantly higher score than all the QMix groups ($P < .05$). Although a noticeable smear layer and occluded dentin tubules remained on the apical surface (scores 3, 4, and 5), the QMix + CSI group showed improved cleaning compared with the negative control groups in all thirds (Fig. 3). Both the QMix + EA group and the QMix + PIPS group showed a significantly better effect than the QMix + CSI group in the coronal third ($P < .05$). In the middle third of the canal, the QMix + EA group revealed superior smear layer removal compared with the QMix + Er:YAG group and the QMix + CSI group ($P < .05$), with no significant difference compared with the QMix + PIPS group ($P > .05$). In the apical third of the canal, the QMix + EA group and the QMix + Er:YAG group showed improved cleaning compared with the nonactivated QMix group ($P < .05$).

In the comparison of intragroup findings according to thirds of the root canal (Table 2), the highest scores were found in the apical third ($P < .05$) followed by the middle and the coronal thirds in all experimental groups. There were significant differences between the coronal and middle thirds in the QMix + PIPS and QMix + Er:YAG groups, but no difference was found in the coronal and middle thirds of the QMix + CSI and QMix + EA groups.

Discussion

Dai et al (6) and Stojicic et al (7) concluded that QMix solution is as effective as 17% EDTA in removing canal wall smear layers from the entire root canal space. However, previous studies concluded that it is difficult to achieve total elimination of the smear layer by using needle irrigation (24, 25). Additionally, because of vapor lock that results in trapped air in the apical third of the root canals, the effectiveness of irrigating solutions remains limited in the apical one third (14). To further investigate these findings, the present study evaluated whether using the EA system, PIPS, and an Er:YAG laser with a 300-μm endodontic fiber tip improves the efficacy of QMix in the coronal, middle, and apical thirds.

Because of the similarities to clinical situations (root is enclosed by the bone socket), a closed-end canal model was used in the current study (14). Root canal instrumentation was performed with ProTaper nickel-titanium instruments, and canals were enlarged to an apical

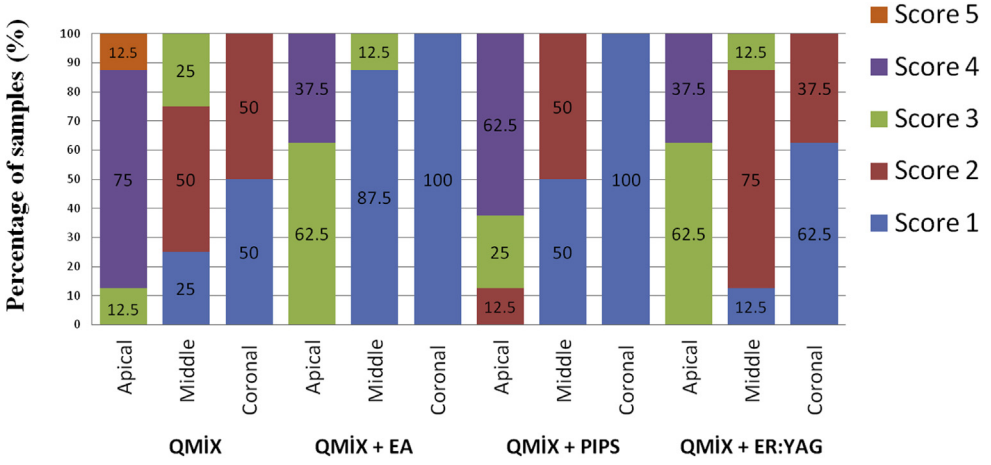


Figure 1. Distribution of smear scores (in %) in the apical, middle, and coronal thirds of the root canal in the QMix groups.

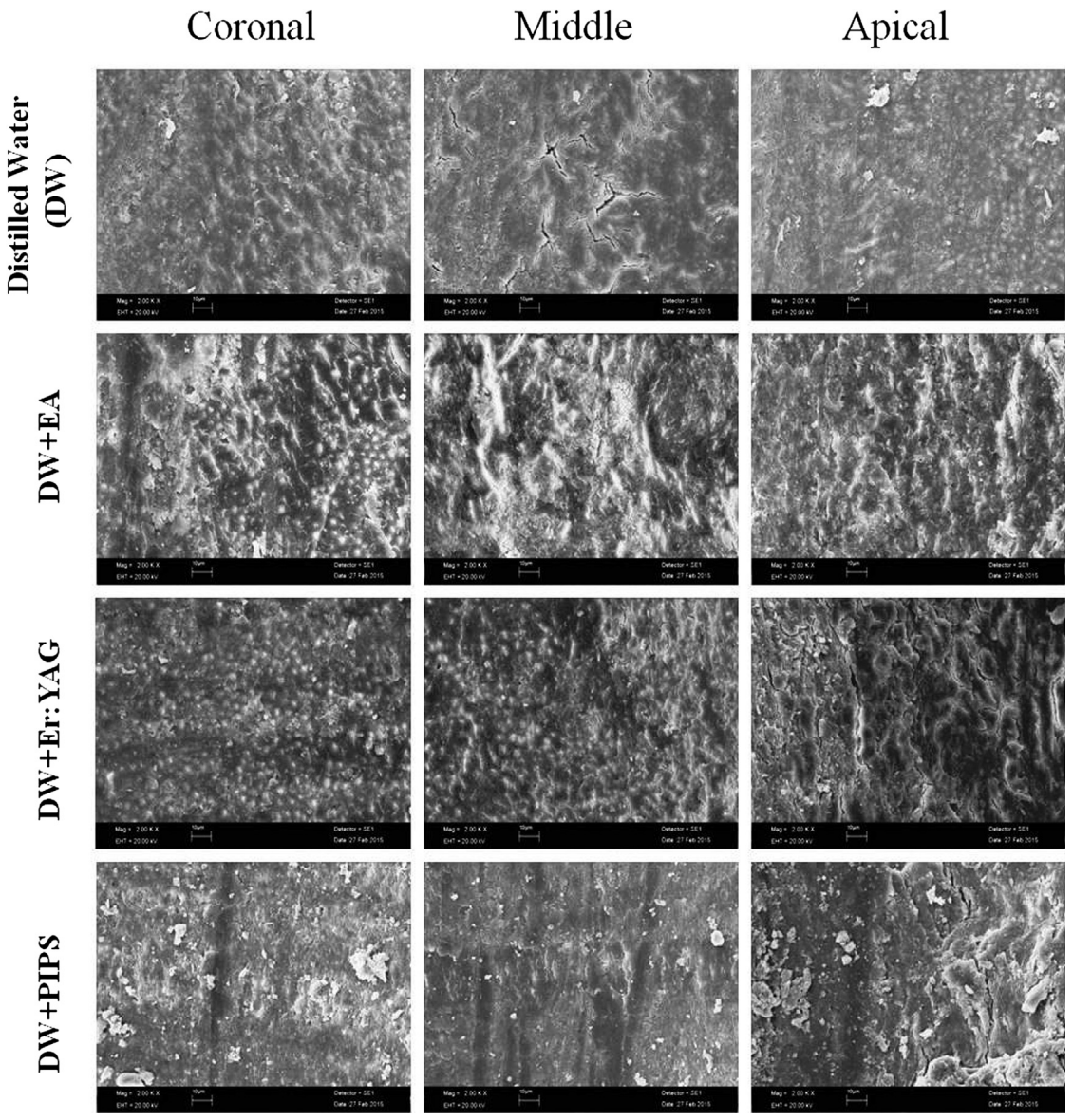


Figure 2. Representative scanning electron microscopic images showing selected samples from the coronal, middle, and apical thirds representing the different irrigant activation techniques used with distilled water (magnification 2000×).

size of a 40/0.06 file to allow adequate penetration of solutions to the apical third and to improve the performance of irrigation activation.

Examination of the surface of the root canals in all the control groups (activated or nonactivated distilled water groups) revealed the presence of a homogenous smear layer (score 4) or a heavy nonhomogenous smear layer (score 5). These findings suggest that all of the activation methods that were used in the present study have no effect on the smear layer because the smear layer was not removed in the distilled water activated with these methods. Therefore, the improved smear layer removal effect of the activation in conjunction with QMix irrigation may have been achieved directly by the activated QMix irrigant.

Regarding the total mean scores of the apical thirds, the QMix with conventional needle irrigation group had the highest smear scores when compared with the activated QMix groups. This might be attributed to irrigant activation techniques, which may be helpful in breaking the vapor lock effect and may have permitted fluid penetration into the dentinal tubule (26).

Analyses of the data showed that the EA system performed a statistically significant increase in smear layer removal when compared with QMix with the conventional needle irrigation group in all thirds of the root canal. These results are in agreement with Mancini et al (27), Caron et al (13), and Niu et al (28), who showed significantly better smear layer removal with the EA system than without agitation. On the other hand, Uroz-Torres et al (29) reported no significant improvement of smear layer removal with the EA. This contrast was probably because of a different study design and the activation protocols used. Additionally, Al-Jadaa et al (15) suggested that the wavelength of the sonic setup is too long to induce sufficient streaming of the irrigant and that the energy is too low to activate the irrigant.

Laser-activated irrigation has been introduced to supplement conventional endodontic cleaning procedures (20, 21). The mechanism for the laser activation of irrigating solutions originates from the absorption of laser energy; formation of vapor bubbles; collapse of the bubbles; acoustic streaming; and, finally, cavitation (30). In the current study,

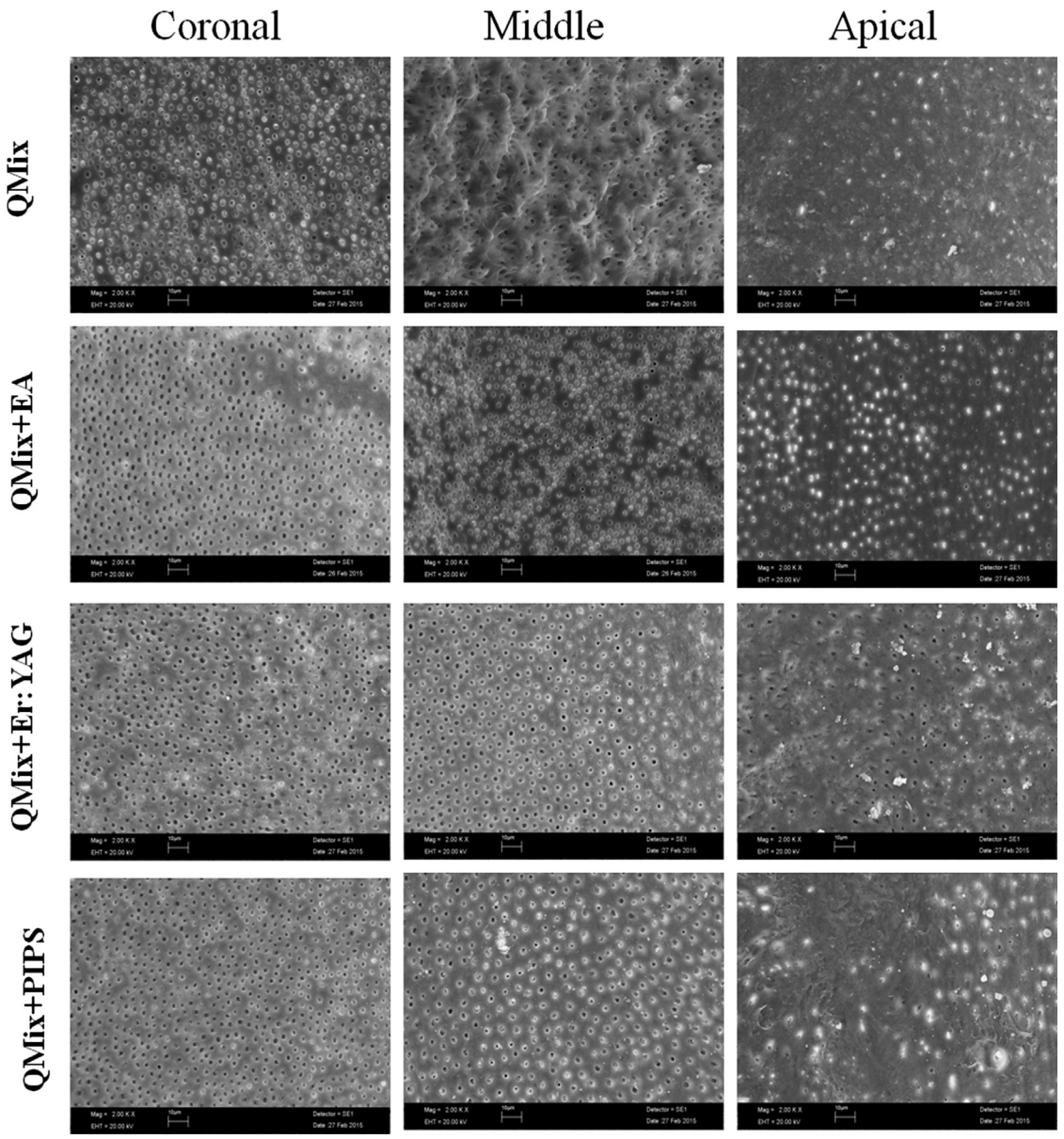


Figure 3. Representative scanning electron microscopic images showing selected samples from the coronal, middle, and apical thirds representing the different irrigant activation techniques used with the QMix solution (magnification 2000×).

we used the Er:YAG laser, which has a high absorption wavelength in water, and hydroxyapatite with an R14 handpiece that had a 300-μm endodontic fiber tip (Preciso). The protocol was set to 1 W, 20 Hz, and 50 mJ. Our results revealed that the Er:YAG laser used to activate QMix irrigation with an endodontic fiber tip had a positive effect in removing the smear layer on the apical and coronal thirds of the root canal. This is consistent with previous studies reporting an increased smear layer removal effect with irrigant activation using the Er:YAG laser with an endodontic fiber tip (21, 31). This can be attributed to the mechanism of the laser as described. Using a laser at ablative settings, large elliptical bubbles were created that can cause an expansion in volume of up to 1600 times the original volume, after which the bubbles collapse and cavitation effects occur. This process can allow the irrigants to access the apical third more easily.

Previous studies have shown that the use of erbium lasers within the root canal may result in side effects. Kimura et al (32) monitored a temperature increase of up to 6°C. Matsuoka et al (33) observed carbonization and cracks on the root canal walls when the laser tips were used for root canal preparation. The development of new techniques like PIPS has been an attempt to prevent these side effects (19). This technique uses low energy levels and short microsecond pulse rates (20 mJ at 15 Hz, 0.3 W average power) to generate peak power spikes. Therefore, PIPS generates a minimal thermal effect. A study with thermocouples applied to the radicular apical third revealed only a 1.2°C thermal rise after 20 seconds and a 1.5°C rise after 40 seconds of continuous radiation (16). When the light energy is pulsed in a fluid, a photomechanical effect occurs rather than a thermal effect. There is another advantage; this technique allows for minimally invasive preparation of the root canal because of tips placed into the canal orifice (34). DiVito et al (16) reported that laser-activated EDTA irrigation with PIPS tips resulted in a significantly better cleaning of the root canal walls in comparison with the conventional irrigation procedures.

TABLE 2. Means and Standard Deviation (SD) Score Values of the Smear Layer for Different Activation Techniques in the Apical, Middle, and Coronal Thirds with QMix

	Mean ± SD			
	QMix + CSI	QMix + EA	QMix + PIPS	QMix + Er:YAG
Coronal	1.50 ± 0.53[a]	1.00 ± 0[a]	1.00 ± 0[a]	1.38 ± 0.52[a]
Middle	2.00 ± 0.76[a]	1.25 ± 0.71[a]	1.5 ± 0.53[b]	2.00 ± 0.53[b]
Apical	4.00 ± 0.53[b]	3.38 ± 0.52[b]	3.50 ± 0.76[c]	3.38 ± 0.52[c]

CSI, conventional syringe irrigation; EA, EndoActivator system; PIPS, photon-initiated photoacoustic streaming.

Friedman test. Means with different superscript letters are statistically different within each column according to the Mann-Whitney *U* test.

Pedulla et al (22) and Zhu et al (35) showed that it results in significantly better removal of the smear layer. In the present study, laser-activated QMix irrigation with a PIPS tip showed better smear layer removal than QMix irrigation with conventional syringe irrigation in all regions. However, these positive effects were found to be statistically significant only in the coronal region. Therefore, we could speculate that the PIPS technique shows a strong agitation of the liquids inside the canals, but penetration of the laser tip is a critical factor for the apical smear layer.

The activation techniques used in this study showed superior effects using QMix. However, in order to define the methodological limitations found in conventional score-based smear layer removal, the scanning electron microscopic studies, and the lack of simulated clinical practice, further *in vivo* investigations of solution activation systems are needed for an appropriate evaluation of the cleanliness of canals.

Conclusions

Under the conditions of this study, it was found that the Er:YAG laser, PIPS, and EA techniques enhanced the smear removal capacity of the QMix solution when compared with needle irrigation. Er:YAG laser–activated QMix removed the smear layer more effectively than other techniques in the apical third of the root canal system, whereas PIPS had the same effect in the coronal third.

Acknowledgments

We would like to thank for Professor Aslıhan Usumez supporting the laser device.

The authors deny any conflicts of interest related to this study.

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