A Comparative evaluation of smear layer removal using: sonic, ultrasonic, and erbium, chromium: yttrium scandium gallium garnet Laser as activated irrigation techniques (an SEM study)

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Background and Objectives: In root canal treatment it is important to provide a reliable method that effectively removes the smear layer to ensure more successful results in endodontic treatment. This study aims to compare the efficacy of different irrigant activation methods (sonic, ultrasonic, and erbium, chromium: yttrium scandium gallium garnet Er,Cr:YSGG—2780nm laser) for the removal of smear layer at coronal, middle, and apical one-third of the root canal surface.

Methods: Sixty single-rooted mandibular premolar teeth were selected and instrumented to size 25/.08 (HyFlex EDM, Coltene). Samples were randomly divided into 4 groups of 15 roots each, depending on the system used to activate the irrigant solution. Group1, conventional needle irrigation with no activation (control), Group2 activated by EndoActivator (sonic group), Group3 activated by UltraX activator (ultrasonic group), and Group4 activated by Er,Cr:YSGG laser (laser group). Samples were irrigated with 1ml of EDTA 17% for 1 minute, then received 5ml of NaOCl 5.25% and activated for 1 minute. Scanning electron microscope investigations were conducted to evaluate the efficacy of suggested treatments.

Results: Laser group showed the least smear layer scores, followed by ultrasonic then sonic groups with no statistically significant differences. All groups revealed better smear layer removal compared to the control group with significant differences at (p-value < 0.05).

Conclusion: All the activation techniques were useful in the removal of the smear layer with the favorite to laser technology that was the best one. Smear layer removal was more effective in the coronal and middle thirds than in the apical third for all groups.

Keywords: Irrigation, Smear layer, Sonic, Ultrasonic, Laser

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Introduction

The primary requirements of successful root canal therapy are effective chemomechanical preparation and three-dimensional obturation of the root canal system.[1] A smear layer is produced on the root canal walls during root canal preparation and is composed of organic and inorganic substances like as mineralized dentin particles, predentin, biofilm, bacteria, and their metabolic products.[2] The smear layer should be eliminated before canal obturation to increase endodontic sealer adherence and penetration, resulting in a better seal.[3]

Intracanal irrigants such as sodium hypochlorite (NaOCl) are usually used first, followed by ethylenediaminetetraacetic acid (EDTA), both of which are injected into the canal with a needle and syringe. The organic components of the smear layer are dissolved by NaOCl, while the inorganic components are removed by EDTA. The most efficient approach for removing a smear layer is to combine NaOCl (0.5%–5.25%) and EDTA (15%–17%) solutions.[4,5]

Sonic systems with a frequency of 1–10 kHz can clean the root canal system using special

canal instruments that work with air pressure by vibrating in horizontal and vertical movements without rotating. The EndoActivator is a sonic irrigation activation device from Dentsply in which the irrigation fluid is moved at a specified speed and strength by the non-cutting polymer tip.[6]

The ultrasonic irrigation method has been shown to successfully remove the smear layer, dentin debris, microorganisms, and organic tissue from the root canal space. Passive ultrasonic activation (PUA) at a frequency of 25 to 30 kHz works by transferring acoustic energy from a vibrating instrument to the root canal irrigation solution. Ultrasonic waves carry the energy, which causes irrigant cavitation and/or acoustic streaming.[7]

Lasers can be used to clean root canals and remove the smear layer. Erbium, chromium: yttrium scandium gallium garnet (Er,Cr:YSGG) laser is a well-studied wavelength that has been confirmed to have numerous advantages. Er,Cr:YSGG emits photons at a wavelength of 2780 nm. This wavelength has strong absorption in water and hydroxyapatite, making it ideal for removing smear layers and possibly reducing microbes during root canal treatments.[8]

In root canal treatment it is important to provide a reliable method that effectively removes smear layer from all parts of the root canal surface and to ensure more successful results in endodontic treatment.

Methods

Samples Collection and Selection

In this study, a total of sixty human single-rooted mandibular premolar teeth freshly extracted for orthodontic reasons in age range (18 to 35-year-old patients) were collected. The teeth were cleaned by washing them under distilled water, then soft tissue remnants were removed using an ultrasonic scaler, after that samples were stored in a plastic container containing 0.1% thymol solution for disinfection.[9] Each tooth was examined with a periapical radiograph both buccolingually and mesiodistally with (Vatech - EzRay, South Korea) X-Ray Unit. An inclusion criterion included a straight root with a single canal, a tooth with a mature and closed apex, no previous endodontic treatment, no visible cracks in the roots, absence of root decay, absence of internal resorption, and root length of at least 13mm. The roots that had caries, cracked, fractured, immature apexes, dilacerated roots, or had resorption when examined under a magnifying dental loupe (X10) were discarded.

Sample Preparation

The root length was standardized to 12 mm from the anatomic apex by sectioning the crowns of whole samples using a double-faced diamond disc (Drendel + Zweiling, Germany) mounted on a slow-speed conventional straight handpiece. After decoronation, a stainless steel K-file #10 (FKG, Switzerland) was inserted slowly until it was visualized at the apical foramen by the naked eye. The working length was determined by subtracting 0.5 mm from the length, and then the samples were stored in isotonic saline in their vials.

The root apices were sealed with sticky wax (Polywax toughened dental modeling wax, Bilkim company, Turkey) to prevent extrusion of the irrigants through the apical foramen and to simulate the closed-end system during chemomechanical preparation.[10] To facilitate the handling of the samples during the working steps, the samples were embedded in a custom-made plastic water pipe containing silicon rubber base polysiloxane impression material (putty consistency) (Turbosil, R&S, France).

Root Canal Instrumentation

The biomechanical preparation of the root canals was accomplished using HyFlex EDM rotary NiTi files (COLTENE, Germany). The sequence began with the orifice opener (25/.12), followed by the glide path file (10/.05), and HyFlex OneFile (25/.08) at a speed of 400 rpm and a torque of 2.5 Ncm, following the manufacturer's recommendation. The files were used in 15 pecking strokes until they became loose at full working length, a gentle in-and-out pecking motion with light apical pressure was applied to the instruments.[11] After each file, apical patency was checked with a #10 K-file, and the canal was irrigated with 1.0 ml of 5.25% NaOCl using a 31-gauge double side-vented irrigation needle that was placed 2mm shorter than the determined working length.[9]

Samples Grouping

The sixty root samples were randomly divided into four main groups, depending on the system used to activate the irrigant, (n=15) for each of these four groups.
Group1 : control group (without activation), Group2 : EndoActivator (sonic activation), Group3 : Ultra X activator (ultrasonic activation), and Group4 : Laser activator (Er:Cr:YSGG laser 2780nm).

Final Irrigation Protocol

Each sample was irrigated with 1 ml of EDTA 17% for 1 minute, after that, the sample received 5 ml of NaOCl 5.25% and activated while the irrigant was inside the canal according to the groups mentioned above then received the final rinse of 5 ml distilled water and dried with a paper point.

Activation Method for All Groups

G1/ Control Group (n=15):

Activation of irrigant using conventional needle irrigation (NaviTip, Ultradent Products, USA). The needle was placed 2mm shorter than the determined working length and moved up and down 2-3mm. **G2/ Sonic Activation (n=15):** Activation of irrigant using sonic- activated irrigation Endoactivator (Dentsply Maillefer, Switzerland). The medium-size polymer tip (red tip) size (25/.04) was used to clean the canals. The tip was attached to an Endoactivator device fitted passively inside the canal 2mm shorter than the working length, and activated at 10,000 CPM for 60 seconds in three cycles of 20 seconds each, with pumping action in short 2-3mm vertical strokes.[3]

G3/ Ultrasonic Activation (n=15):

Activation of irrigant using ultrasonic activated irrigation (Ultra X, Eighteeth, China). The stainless steel non-cutting wire S21 (size 25\0.02, 21mm long) silver tip was driven by Ultra X device at "High Output Power Mode" (frequency 45 kHz), in 3 cycles of ultrasonic activation for 20 seconds. The activator tip was held 2 mm from the apical stop in the centre of the canal, and 2-3 mm apical-coronal pumping motions were done to give each canal 1 minute of passive ultrasonic irrigation.[12]

G4/ Laser Activation (n=15): Activation of irrigation using Er,Cr:YSGG laser. Agitation with Er,Cr:YSGG pulsed laser (Biolase, Waterlase, Iplus, CA, USA) with a wavelength of 2780 nm. The delivery was by radial firing tip RFT2 (Biolase Technology), 200 μm diameter and 21 mm long. The fiber tip was applied according to the manufacturer's instructions: Panel setting was Power =1.25 W, pulse energy 25 Microjoule, repetition rate: 50 Hz, pulse duration: 60 μs. The fiber tip was inserted 2 mm from the apex, and in contact mode, a helicoidal movement was performed at a speed of 1mm/s from apical to cervical direction, in three cycles, each cycle was accomplished in 18 seconds cycle and a resting time of 5 seconds resulted in a total irradiation time of 54 seconds.[9]

Root Sectioning and Preparation Protocol for SEM Evaluation

The roots were split longitudinally in the bucco-lingual plane. Two grooves were carved onto the buccal and lingual root surfaces with a diamond disc without entering the inner parts of the canals. Then the roots were split into two halves by placing surgical blade #11 in the groove and striking the blade gently with a small mallet. One half (the completely untouched section of the split root) was divided into three main parts with equal lengths of 4 mm (coronal, middle, and apical thirds).

The dehydration of specimens was done with ethyl alcohol using ascending concentrations of (30–100% for 10 min each), dried in a desiccator for 24 h, and the inner root surfaces were metalized with gold by direct-current chemical vapor deposition. Each sample was evaluated for residual smear layer under a scanning electron microscope SEM (Hitachi-S4160, Japan). Three points were selected at the center of each third and then observed under 1000x and 2000x magnification.

The SEM photographs were coded based on the final irrigation protocol, randomly mixed in a blind manner, and then evaluated by two calibrated examiners. They were going to score the presence or absence of a smear layer on the surface of the root canal according to the following criteria suggested by Torabinejad et al.13

Score 1: No smear layer: absence of any smear layer on the surface of the root canal, with open and clean dentinal tubules.

Score 2: Moderate smear layer: absence of the smear layer on the surface of the root

canal, with dentinal tubules laden with debris.

Score 3: A large amount of the smear layer: complete coverage of the root canal walls with the smear layer, with the dentinal tubules laden with debris.

Statistical Analysis

The data were collected and analyzed statistically using (R version 4.11 and SPSS v. 26). Non-parametric tests were conducted on the collected drawn sample study since the dataset was measured only with three scores. Between groups, the Kruskal-Wallis and Mann-Whitney tests were used to examine the significant differences in the amount of smear layer removal. While for within groups, Friedman and Wilcoxon signed-ranks tests were applied to identify which part of the root canal is mostly affected to be clean and open, and vice versa. In addition, the Weighted Kappa test was computed to detect how close the level of agreement between the two examiners measured smear layer levels. P-value < 0.05 was chosen as the level of statistical significance.

Results

The inter-examiner analysis shows a very good strength of agreement between the two examiners since the weighted kappa values between both examiners were (0.895, 0.813, and 0.843) at the coronal, middle, and apical parts respectively.

(Table 1) provides us with detailed descriptive statistics for all groups and regions. All groups were effective in removing the smear layer on the surface of the roots in the middle as well as coronal areas. However, the apical region seemed to be less affected.

Table 1: Descriptive statistics for all groups and areas.

Canal Areas	Groups	Mean	Median	Mode	Std. Deviation	Minimum	Maximum	Kruskal Wallis (P-value)
Apical	Control	2.400	2.000	3.000	0.604	2.000	3.000	12.502 (0.006)
	Sonic	2.200	2.000	3.000	0.597	1.000	3.000	
	Ultrasonic	1.800	2.000	2.000	0.528	1.000	3.000	
	Laser	1.567	2.000	2.000	0.495	1.000	2.000	
Middle	Control	1.800	2.000	2.000	0.455	1.000	3.000	8.434 (0.038)
	Sonic	1.833	2.000	2.000	0.488	1.000	3.000	
	Ultrasonic	1.567	2.000	2.000	0.495	1.000	2.000	
	Laser	1.367	1.000	1.000	0.380	1.000	2.000	
Coronal	Control	1.667	2.000	2.000	0.488	1.000	2.000	8.027 (0.045)
	Sonic	1.800	2.000	2.000	0.414	1.000	2.000	
	Ultrasonic	1.633	2.000	2.000	0.481	1.000	2.000	
	Laser	1.333	1.000	1.000	0.375	1.000	2.000	

From (Table 1), it was noted that the laser group had the lowest mean values in all three regions, followed by the ultrasonic and then sonic groups. In addition, statistically significant differences were observed between all four groups in apical, middle, and coronal regions based on the Kruskal Wallis test with p-values of 0.006, 0.038, and 0.045 respectively.

Control Group: (Table 1) states that in the apical region the mean value was 2.400, and this can be reported as a high volume of smear layer. In middle and coronal areas, similar results were found with mean values of 1.800 and 1.667 respectively, which means that a moderate smear layer was detected (Figure 1).

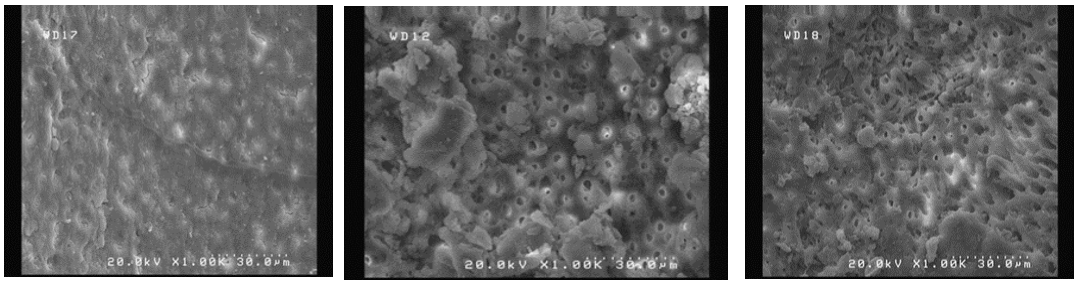

Figure 1: SEM image analyses for conventional needle irrigation with 5.25% NaOCl irrigation solution

Sonic Group: As seen in (Table 1), the sonic group in the apical region had the highest mean value recorded at 2.200. Quite close results were found in the middle and coronal areas, with mean values of 1.833 and 1.800 respectively. Therefore, the sonic group was seen to perform much better in the coronal region compared to other regions due to its low value in the region.

Ultrasonic Group: Different outcomes are perceived in (Table 1), and ultrasonic had lower mean values in all three regions. The mean value of the amount of smear layer was 1.800 in the apical area, which was close to a moderate smear layer, then it dropped to 1.567 in the middle and then it went up slightly to 1.633 in the coronal regions. This indicates that most of the cases in the ultrasonic group were freed and cleaned from the heavy smear layer.

Laser Group: According to the descriptive statistics provided in (Table 1), Er,Cr:YSGG laser turned out to be much more effective in response to removing the smear layer than other groups. This laser reduced the smear layer with a mean value 1.567 in the apical region, while this even dropped by 0.2 more units to 1.367 in the middle and then became even smaller to 1.333 in the coronal region. These results can be interpreted as no smear layer, especially in the middle and coronal areas (Figure 2).

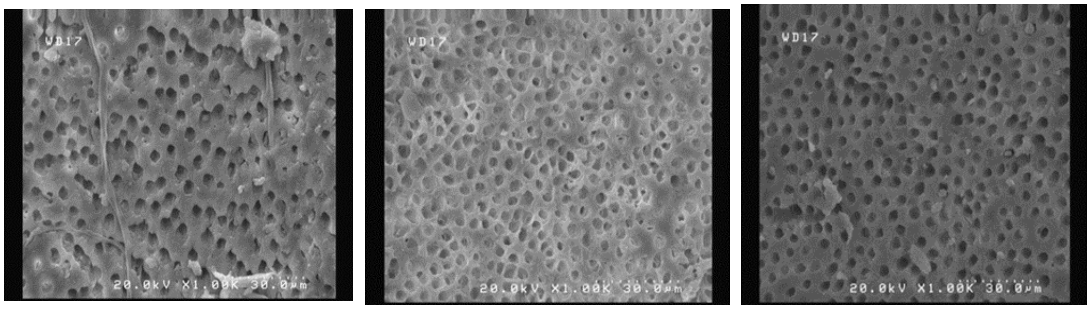

Figure 2: SEM image analyses for Er,Cr:YSGG laser activation with 5.25% NaOCl irrigation solution (A=apical third, B=middle third, C=coronal third).

In the middle part with a p-value (0.038) < 0.05. Mann-Whitney U test showed in (Table 3) that the control group had a statistically significant difference with the laser group. Moreover, the sonic group was found to have a statistically significant difference with the laser group (p-values < 0.05).

In the coronal part with a p-value (0.045) less than 0.05. Mann-Whitney U test was also confirmed in (Table 4) that sonic and laser groups turned out to have a statistically significant difference with (p-value < 0.05).

For each group, it is necessary to highlight if any of the groups work differently per each region and this can be done by using the Friedman test for all three regions together and Wilcoxon signed rank test for pairwise. Comparison Between Groups and Within Groups

The Kruskal-Wallis analysis detected a significant difference between the different groups (p-values < 0.05). In the apical part with a p-value (0.006) less than 0.05, the Mann-Whitney U test was implied for the pairwise multiple comparison test. As shown in (Table 2), the control group was significantly different with the ultrasonic and laser groups. Also, sonic device had a different significant impact compared to laser device with (p-values < 0.05).

(Table 5) presented that sonic, ultrasonic as well as Er,Cr:YSGG laser devices impacted all three root canal parts equally and fail to reject the null hypothesis saying that there is no statistical difference among the pairs where the Friedman test (p-value > 0.05). Whereas the control group showed a significant difference in response to smear layer removal (p-value < 0.05). To investigate this further, Wilcoxon signed rank test was computed and found that statistically significant mean rank differences were recorded between (Apical & Middle) and (Apical & Coronal) root canal regions.

Table 2: Non-Parametric Test for Apical region per group.

Canal Area	Groups	Mean Rank	Mean Value	Mann-Whitney Test (P-value)	Kruskal Wallis (P-value)
Apical	Control	16.47	2.400	98.000 (0.522)	12.502 (0.006)
	Sonic	14.53	2.200		
	Control	19.10	2.400	58.5 (0.015)	
	Ultrasonic	11.90	1.800		
	Control	20.27	2.400	41.00 (0.002)	
	Laser	10.73	1.567		
	Sonic	17.83	2.200	77.50 (0.126)	
	Ultrasonic	13.17	1.800		
	Sonic	18.97	2.200	60.50 (0.023)	
	Laser	12.03	1.567		
	Ultrasonic	17.07	1.800	89.00 (0.273)	
	Laser	13.93	1.567		

Table 3: Non-Parametric Test for Middle region per group.

Canal Area	Groups	Mean Rank	Mean Value	Mann-Whitney Test (P-value)	Kruskal Wallis (P-value)
Middle	Control	15.13	1.800	107.000	8.434 (0.038)
	Sonic	15.87	1.833	(0.791)	
	Control	17.37	1.800	84.50	
	Ultrasonic	13.63	1.567	(0.182)	
	Control	18.87	1.800	62.000	
	Laser	12.13	1.367	(0.020)	
	Sonic	17.63	1.833	80.500	
	Ultrasonic	13.37	1.567	(0.136)	
	Sonic	19.03	1.833	59.500	
	Laser	11.97	1.367	(0.016)	
	Ultrasonic	17.10	1.567	88.500	
	Laser	13.90	1.367	(0.263)	

Table 4: Non-Parametric Test for Coronal region per group.

Canal Area	Groups	Mean Rank	Mean Value	Mann-Whitney Test (P-value)	Kruskal Wallis (P-value)
Coronal	Control	14.50	1.667	97.500	8.027 (0.045)
	Sonic	16.50	1.800	(0.417)	
	Control	15.83	1.667	107.500	
	Ultrasonic	15.17	1.633	(0.806)	
	Control	18.17	1.667	72.500	
	Laser	12.83	1.333	(0.063)	
	Sonic	16.90	1.800	91.500	
	Ultrasonic	14.10	1.633	(0.276)	
	Sonic	19.30	1.800	55.500	
	Laser	11.70	1.333	(0.008)	
	Ultrasonic	17.97	1.633	75.500	
	Laser	13.03	1.333	(0.090)	

Table 5: Comparisonbetween regions for each group

Groups	Apical Mean Rank	Middle Mean Rank	Coronal Mean Rank	Friedman Test (P-value)	Wilcoxon Signed Ranks Test
Control	2.530	1.830	1.630	8.933 (0.011)	(A-M)*, (A-C)*
Sonic	2.400	1.870	1.73	4.766 (0.092)	
Ultrasonic	2.170	1.830	2.000	1.250 (0.535)	
Laser	2.230	1.870	1.900	2.114 (0.347)	

* Statistically significant with <0.05

Discussion

A smear layer is produced on the root canal walls during root canal preparation that acts as a barrier between filling materials and the canal wall hindering the successful disinfection of the root canal system. Agitation of irrigation solutions is essential for enhancing root canal system cleanliness.

The present study evaluated and compared the cleaning effectiveness of the different irrigation activation techniques on the degree of smear layer removal at coronal, middle, and apical one-third of the root canal surface.

Conventional irrigation with needles or syringes performed the least in removing debris and smear layer at all thirds compared to the other three groups. Because the irrigating solution is delivered only 1 mm deeper than the tip of the needle.

This limits the penetration depth of the irrigating solution resulting in less effective smear layer removal, especially from the apical third.14 In the sonic group the results were close to in the control group, the presence of clusters of smear layer and debris, especially in the apical third was obvious, also the dentinal tubules were partially opened in the coronal and middle thirds.

This inadequate performance could be attributed to the low vibration/oscillation frequencies (2–3 kHz), which results in lower streaming velocities and cavitation effects.15 In the ultrasonic group a better removal of the smear layer and debris can be noticed and also an increase in the number of opened dentinal tubules, especially in the middle third, but the dentinal tubules in the apical third were partially occluded. The good result of the ultrasonic device is due to the possibility of increasing contact of the liquid with the canal walls (higher oscillation frequency 25-40 kHz).16 Laser group presented the lowest scores in the removal of the smear layer. The smear layer was removed at the whole root regions specifically in the coronal third.

This powerful and effective result of Er,Cr:YSGG laser due to the high affinity of 2780nm laser wavelength to the irrigant solution, and this fluid absorption led to effective cavitation and powerful shock waves.[17]

All the groups performed smear layer removal better than the control group, as many studies have proved.[4,9] Passive ultrasonic irrigation (PUI) produced significantly cleaner canals than passive sonic irrigation at all canal thirds, which is similar to the present results.[18,19] In contrast, some studies showed that sonic irrigation is superior to ultrasonic irrigation activation.[20,2]

The reason may be that PUI creates the undesirable dampening effect of amplitude of its characteristic nodes and antinodes patterns, especially when the instrument touches the lateral walls of a shaped canal. While sonic activation operated with one single positive and negative node, the movement of the vibratory sonic instrument was not influenced by lateral wall contact.[21]

The laser group achieved better smear layer removal than the sonic group, which is supported by the results obtained by.[9,22] Conflicting results in published studies,[4,23] might be attributed to the fact that they used in laser group a lower volume of irrigant solution, which was 1ml, and also irradiated for less duration (20 seconds) than in this study. Also, laser-activated irrigation was more effective in removing the smear layer than the ultrasonic device. This is in accordance with.[24,25]

Regarding different thirds for all groups, removal of the smear layer was significantly more effective in the coronal and middle parts than in the apical part. This is because for many reasons: Firstly, the taper and diameter of the apical third are much smaller than those of the coronal and middle which in turn hinder the circulation and action of irrigating solution. Secondly, dentin at the apical region is sclerotic and transparent, has a more irregular structure and reduced permeability compared to dentin of coronal or middle root third. Thirdly, inadequate debridement in the apical region may have resulted from the apical vapor lock effect.[8]

This result is in agreement with the findings of,[23,26] and also is in contrast to studies.[9,27] The reason is due to the apical enlargement,

they enlarged apical preparation to 40/0.06, which exposes the dentine to a higher volume of irrigants in the apical third, hence allowing for better removal of the smear layer in this area.

Conclusion

Based on the results of this study, the activation of irrigants via sonic, ultrasonic, or laser devices has shown great improvement in the cleaning of the root canal system when used with EDTA + NaOCl solutions. Er,Cr:YSGG laser was pointed out to be the best technique in attempting to remove the smear layer among the others, followed by ultrasonic and then sonic devices. The cleanest dentinal tubules were found in the coronal third, followed by the middle and then the apical thirds.

Conflict of interest

The author reported no conflict of interests.

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