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ORIGINAL ARTICLE

Assessment of the Effect of Different Irrigation Protocols on the Penetration of Irrigation Solution into Simulated Lateral Canals (*In Vitro* Study)

Ahmed Qasim TALIB, Hussain F. AL-HUWAIZI

Department of Conservative Dentistry and Endodontic, University of Baghdad College of Dentistry, Baghdad, Iraq

ABSTRACT

Objective: To compare the effectiveness of lateral canal irrigation penetration by conventional needle, passive ultrasonic, sonic endo activator, and Erbium laser (2780nm).

Methods: A total of 40 palatal roots of human maxillary first molars were collected and instrumented at a working length of 12 mm by an X1-X4 rotary Protaper Next system (Dentsply, Maillefer, Ballaigues, Switzerland) using the crown-down technique. Artificial lateral canals were made at 2, 4, and 6 mm from the apex on mesial and distal sides using an ISO rotary reamer (Dentsply, Maillefer, Ballaigues, Switzerland; #10 for mesial, #08 for distal). The samples were then cleared using methyl salicylate. A solution of black ink and normal saline was used as an irrigant for the root canal. The percentages of the penetration of the ink into the lateral canals were measured using a stereomicroscope (Q-Scope, Arnhem, The Netherlands) with the aid of program Image J. The Tukey test is used to assess the significant difference between intragroup and intergroup comparisons of different thirds, and the T-test is used to assess the significant difference between every two groups and for the mesial and distal sides of each group. The level of significance was set at 0.05.

Results: Results showed that none of the activation techniques used resulted in complete lateral canal penetrations; however, on both sides at all thirds, the Erbium laser (2780 nm) achieved the highest results with a highly significant statistical difference ($p=0.05$) with all other groups, and the least penetration was in the conventional needle group.

Conclusion: The size of the lateral canal is a restricting factor for all activation methods; the best results can be achieved by laser. Conventional needles cannot be used alone to disinfect complex canal anatomy; however, passive ultrasonic and sonic endo activator activations can produce comparable results.

Keywords: Conventional needle, irrigation, laser activation, lateral canals, passive ultrasonic activation, sonic endo activator

HIGHLIGHTS

- The percentage of lateral canal penetration by the irrigant was higher when agitation methods were used to activate the irrigation solution than conventional irrigation with a needle, so conventional needle irrigation cannot be relied upon alone to irrigate and disinfect the lateral canals.
- The best lateral canal penetrations could be achieved with laser activation, and endo activators and passive ultrasonics could be used to enhance lateral canal disinfection comparably.
- The lateral canals at the apical third of the root canal are the most challenging area to clean and irrigate, but with the use of laser activation, the difficulty could be diminished.
- All of the methods tried did not result in completely penetrated lateral canals along the canal walls.
- The size of the lateral canals was a restricting factor for all activation methods.

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Address for correspondence:
Ahmed Qasim Talib
Department of Conservative Dentistry and Endodontic, University of Baghdad College of Dentistry, Baghdad, Iraq
E-mail: ahmedtalib1992@gmail.com

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INTRODUCTION

Successful endodontic treatment requires that all the vital and necrotic pulp tissue, as well as the microbes and their toxins, be removed. However, the complex root canal anatomy has made it difficult for total debridement (1, 2). It's possible that the complex root canal structures, which include an accessory or lateral canal, may go unnoticed. These auxiliary canals can be found anywhere along the path of the main root canal, although they are typically found where the roots of multi-rooted teeth unite or in the terminal third of the root. Accessory canals can occasionally be challenging to locate, clean, and fill (2). Lateral canals can support bacterial colonisation and are hard to instrument and irrigate through endodontic therapy (3, 4). Other investigations confirmed their potential pathogenicity following the healing of peri-radicular lesions in connection to the full obturation of lateral canals, despite Barthel et al. indicating no link between unfilled lateral channels and infection of the periodontal ligament (4, 5). For a root canal procedure to be effective, efficient instrumentation, irrigation, and obturation of the canal must all be used. The periapical tissues' rate of recovery is most affected by the irrigation of the root canal, which is one of these three essential steps in root canal therapy (4). Irrigations can assist mechanical debridement by removing debris, dissolving tissue, and cleansing the root canal system. Chemical debridement is especially important for teeth with complex internal architecture, such as fins or other abnormalities that instruments could miss (6, 7). *In vitro* studies have existed and were set out in a direction to resemble the outcomes of various irrigation processes with further agitation methods to enhance the effectiveness of the irrigant and deliver it to all root canal surfaces. Artificial lateral canals of various forms and sizes were made for this purpose utilising a variety of techniques, like a split and hinged hard metal model with lateral canal-like extensions on the main canal (7, 8), while other authors suggested resin blocks with a lateral canal-like extension on the main canal (9, 10).

As there is limited information about lateral canal irrigation and how the size of those canals can affect their irrigation, the present study was carried out to develop a standardised model system to examine four endodontic irrigation techniques (conventional irrigation (CI), passive ultrasonic irrigation (PUI), sonic irrigation, and Erbium laser (2780 nm)) and evaluate and compare the effectiveness of these activation methods on the penetration of irrigation solution into artificial lateral canals (ALC) of two different sizes. The null hypothesis tested was that there is no significant difference in lateral canal penetration of the different sizes between the activation groups.

MATERIALS AND METHODS

Sample Preparation

The research proposal was approved by the local Research Ethics Committee of Baghdad University, College of Dentistry (Registration No. 507522). The study was conducted by the Declaration of Helsinki. A total of 40 freshly extracted human maxillary first molar teeth from subjects indicated for extraction were used in this study. After cleaning the teeth with distilled water, soft tissue remains were removed with an ultrasonic scaler, and the teeth were then carefully polished with pumice. The samples were then kept in a plastic container with a 0.1% thymol solution for disinfection after being removed from any exterior debris, such as pumice particles, by using an ultrasonic bath for five minutes (11). To confirm the existence of a mature apex, lack of resorption, or endodontic obturation, teeth were then radiographed mesiodistally and buccolingually. Inclusion criteria included teeth that have solitary canals with a straight palatal root and no laterally positioned apex, lack of root decay, no previous endodontic treatment, lack of internal resorption, a root length of at least 14 mm and a maximum apical diameter of ISO size 15, and no visible cracks in the roots. The length of the roots was regulated to be 12 mm using a digital caliper and a permanent red marker. After placing the teeth in a bench vice, a double-faced diamond disc mounted on a slow-speed handpiece was used to segment the roots of each tooth perpendicular to its long axis per the sketched line (11). Using a #10 stainless steel K file (M ACCESSTM, Dentsply Maillefer, Switzerland), each root canal's original negotiation length was decreased by 0.5 mm to determine the working length. To facilitate handling throughout the working processes (instrumentation, irrigation, and activation), the samples were inserted within a plastic tube with silicone rubber base impression material (putty consistency). A hole was drilled in the base of the plastic tube to allow air to escape while the silicon putty was introduced (11). The silicone putty and catalyst gel were mixed and deposited in the plastic container as directed by the manufacturer. The sample was then submerged in the silicone putty while being surveyed to make sure its long axes were parallel to the tube's long axis. The silicon material was then left until being set. Plastic tubes were then moved into place by a bench vice to achieve a standardised position during the working procedure (11). ProTaper Next rotary NiTi files (Dentsply Maillefer, Ballaigues, Switzerland) were used for the instrumentation, which was carried out utilising the crown-down approach using an endodontic micromotor (Eigheeth, China) at 300 rpm and 2.0 Ncm of torque.

Formation of Lateral Canals

After the instrumentation is finished, three pairs of artificial lateral canals were prepared on the proximal sides of the roots (mesial and distal) at 2 mm (apical third), 4 mm (middle third), and 6 mm (coronal third) from the apex perpendicular to the root surface measured by an endo ruler using an engine reamer (#10 on the mesial surface, #8 on the distal surface) driven by NSK contra-angle with water coolant until reaching the shaped canal, and the communication between the artificial lateral canals and the shaped canal is confirmed by K file #8. After the formation of lateral canals is complete, the samples undergo a clearing procedure (12).

Samples Grouping

The samples were randomly divided into four groups, each group with ten teeth:

Group 1: Conventional irrigation with a hypodermic syringe.

Group 2: Passive ultrasonic irrigation.

Group 3: Sonic-activated irrigation.

Group 4: Erbium laser(2780nm) activated irrigation.

The irrigation will be done by using normal saline with a dye (Black ink) to give a good color contrast as the sodium hypochlorite reacts with ink, therefore, we cannot mix them.

Activation of Irrigant Fluid

1. Using conventional needle irrigation

A 31-gauge, 21-long double-sided vented irrigation needle (Navi Tip, Ultradent Product Inc., South Jordan, UT, USA), adapted to a disposable hypodermic plastic syringe, with 5 ml of irrigant (normal saline with black ink), was connected to it, and the needle was positioned 2 mm shorter than the estimated working length (13). The procedure of activation was done in 60 seconds over three cycles of 20 seconds. The needle moved 2–3 mm up and down for activation.

2. Using a sonic-driven endo activator

The endo activator (Dentsply, Maillefer, Ballaigues, Switzerland) was fixed within the surveyor's arm to ensure standardisation throughout the activation procedure and used according to the manufacturer's instructions: The medium-sized polymer tip (25/.04) was used for activation. The tip was passively inserted into the canal at a length that was 2 mm shorter than the working length, and it was operated for 60 seconds in three cycles of 20 seconds each at a rate of 10,000 CPM, pumping in brief 2–3 mm up and down strokes (14). Irrigation of a total of 5 ml of irrigants (normal saline with black ink) was carried out between cycles by a 31-gauge double-sided vented needle adapted to a disposable plastic syringe. The activator tip was only used once to activate the irrigant in a single canal, to avoid any distortion in the soft polymer tip that might happen, which could affect the activation effectiveness and so maintain the standardization.

3. Using passive ultrasonic activated irrigation

Ultrasonic activation was performed using the ultrasonic tip, driven by an ultrasonic device (Ultra X, Eighteeth, China) at "High Output Power Mode" (frequency 45 kHz). Twenty seconds are spent in three rounds of ultrasonic activation. Each canal will receive passive ultrasonic irrigation for 1 minute with the tip of the Ultra X held 2 mm from the short end of the working length in the centre of the channel and moved in a 2-3 mm apical-coronal direction. Between the cycles of activation, a total of 5 ml of irrigants (normal saline with black ink) were applied with a 31-gauge double-sided vented needle adapted to a disposable plastic syringe.

4. Using Er:Cr: YSGG laser (2780nm)

Laser stimulation with Er:Cr: YSGG pulses at a wavelength of 2780 nm (Biolase, Waterlase, Iplus, CA, USA). According to the manufacturer's instructions, a radial firing tip with a diameter of 200 m (Biolase Technology) was used for the delivery: Power = 1.25 watts, pulse energy = 25 microjoules, repetition rate = 50 Hz, and pulse length = 60 are the panel's settings. According to the manufacturer's instructions, samples were exposed to radiation in three cycles for a total of 54 seconds, utilising a fibre tip inserted 2 mm below the apex, contact mode, and helicoidal movement from the apical to the cervical direction at a speed of 1 mm/s (15). Between the cycles of activation, a total of 5 mL of irrigation solution (normal saline with black ink) was applied with a 31-gauge double-sided vented needle adapted to a disposable plastic syringe. Each fibre tip was only used once to activate the irrigant in one canal to avoid any distortion in the delicate fibre tip that might happen, which could affect the activation effectiveness and maintain standardization.

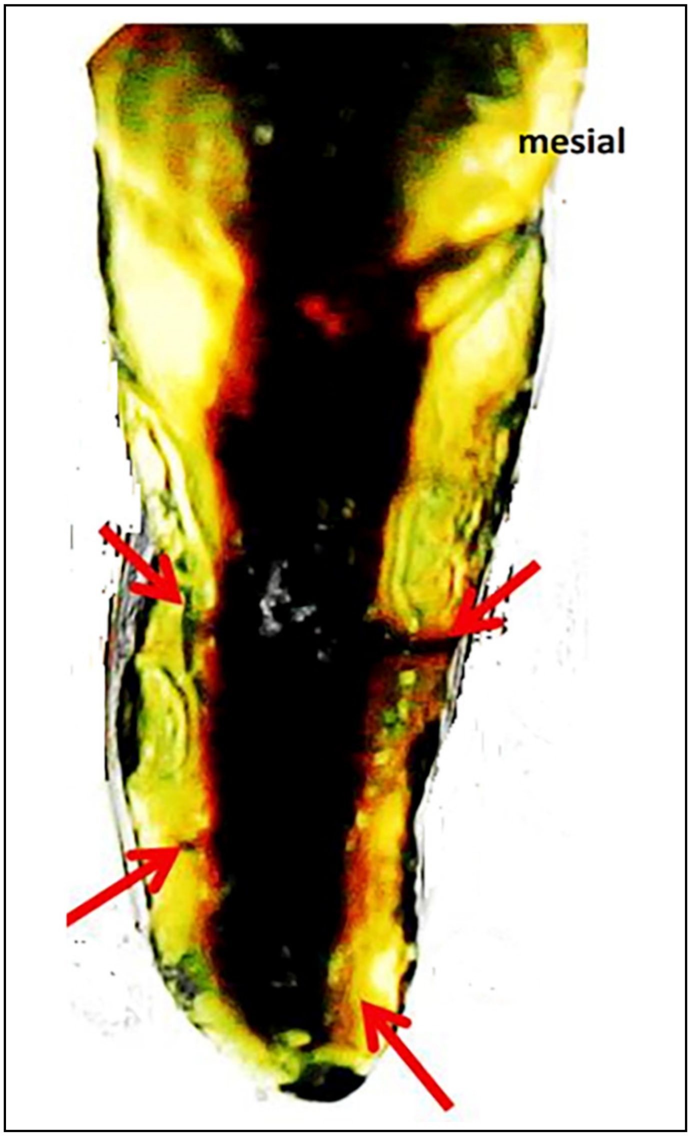

Figure 1. A sample of conventional needle activation group under stereomicroscope at magnification 40X, the red arrows refer to dye penetration of lateral canals

Evaluation of Dye Penetration

Measurement of percentages of dye penetration of the lateral canal done by an image taken by a stereomicroscope under 40 X magnifications (Figs. 1–4). The penetration of the lateral canals was measured linearly on a scale in millimetres with the assistance of the Image J program. The values were obtained by dividing the length of dye penetration by the total length of the lateral canal and multiplying by 100 (16).

Statistical Analysis

The statistical package for social sciences (SPSS Inc., version 26, Chicago, Illinois, USA) was used to carry out the statistical procedures. The data distribution was assessed using the

Figure 2. A sample of sonic endoactivator activation group under stereomicroscope at magnification 40X, the red arrows refer to dye penetration of lateral canals

Shapiro–Wilk test, which showed that the data were normally distributed. The Tukey test was used to assess the significant difference between intragroup and intergroup comparisons of the different thirds. A T-test was used to determine the significance of the difference between each two groups, as well as the mesial and distal sides of each group. The level of significance was set at 0.05.

RESULTS

Among the four activation groups, completely penetrated lateral canals were never seen. The results presented as mean value and standard deviation revealed that the Erbium laser (2780 nm) had a highly significant difference (99.6 0.71; 97.68 3.24); to all other activation groups, followed by ultrasonic (91.8 1.76; 80.13 6.62); and sonic (91 1.61; 80 9.34); and the lowest mean was for the needle group at all thirds and both sides, respectively, as seen in the Table 1. The results also showed that for all groups, the highest mean value of dye penetration was at the coronal third and the lowest at the apical one on both mesial and distal sides, as seen in the Table 2. Table 3 showed that there was a substantial difference between the mesial and distal sides in all activation groups.

Figure 3. A sample of passive ultrasonic activation group under stereomicroscope at magnification 40X, the red arrows refer to dye penetration of lateral canals

DISCUSSION

Inflammatory agents, both vital and nonvital, are most often responsible for pulpal and periapical infections. The vital irritants include microscopic organisms including bacteria, yeast, and viruses (17). To get rid of any persisting germs and prevent additional contamination, the patient should get root canal treatment when the dental pulp has a pathological alteration. The complexity of the root canal system, which includes the presence of numerous and different sizes of lateral canals in the roots, microbial invasion of the dentinal tubules, and the creation of a smear layer during instrumentation may all make thorough root canal cleaning and shaping challenging (18). As a result, dentists must consider the presence of these challenges during cleaning and shaping root canals (19). The efficacy of root canal cleaning is determined by the extent to which the debris and smear layer is eliminated. As a consequence, irrigation is an important step in root canal debridement because it enables comprehensive cleaning of the canal, even in regions where the instruments cannot reach (20). The irrigants' activity

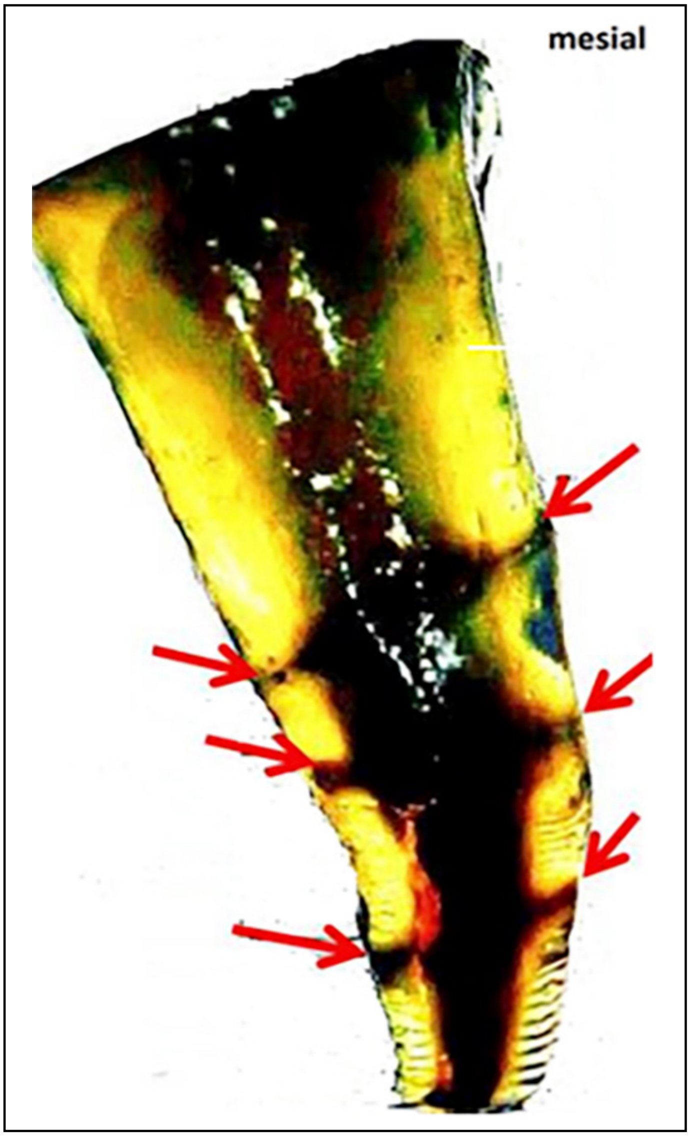

Figure 4. A sample of Erbium laser (2780nm) activation group under stereomicroscope at magnification 40X, the red arrows refer to dye penetration of lateral canals

depends on their making full contact with the canal wall (21). In the case of traditional needle irrigation, fluid exchange and resupply are limited to a little region just beyond the needle's tip. The so-called "vapour lock" phenomenon, which occurs when air is trapped in a region of the root canal, may reduce the efficacy of irrigation (22). The degree of contact and surface tension of chemical irrigants inside the root canal may be increased or decreased using various mechanisms (cavitation, acoustic streaming, shock waves, and the photothermal effect) and irrigant activation systems to enhance canal cleaning after mechanical instrumentation (23). Since there are no existing studies that evaluate the features of all these systems for the debridement of lateral canals of different sizes, this study compared traditional needle irrigation, the endo activator system, passive ultrasonic system, and the ER:CR: YSGG laser (2780nm) *in vitro* to determine how well they infused irrigant solution into artificial lateral canals of two different sizes.

Since almost all palatal roots are classified as Vertucci type I, freshly extracted upper first molars were collected, and the palatal roots with a single straight canal were used for the investigation (24). Because if the crown were present in each tooth, it would have its access design and because a flat reference point for measurements would be more useful without the crown, all the roots were sectioned at a length of twelve millimetres perpendicular to the long axis of the root canal.

Root canals were prepared to size 40/06 X4 (Protaper Next, Dentsply) to ensure that the irrigation was given at the proper length and had enough room for proper flow, and the roots were then lodged in a silicone mould in a plastic tube to establish a closed system to mimic the clinical settings.

Conventional needle irrigation, the endo activator system, passive ultrasonic activation, and the ER:CR: YSGG laser were the methods of agitation used on the samples. In traditional needle irrigation, a 31-G irrigation needle was used to improve needle depth and ensure that irrigation reached the apical portion of the canals (25). The endo activator's tip size, which is size 25/.04, corresponds to that of a needle. The biggest tip that could fit passively within 2 mm of the working length with this device was this one. Based on the manufacturer's advice, this size was chosen to optimise acoustic streaming within the canals. While a silver tip for the ultra X activator of size 25/0.4 was used to standardise the size with endo activator system tips. Due to the Er, Cr: YSGG (2780) laser's strong affinity for (-OH) in water molecules, it was employed in endodontic therapy to clean and irrigate the canal and provide a clean dentine surface (26).

TABLE 1. Shows the descriptive analysis including (Mean, SD, minimum, maximum), of each of activation groups

Side	Group	Mean (%)	±SD	Min	Max
Mesial	Conventional needle (n=30)	56	10.14	40.00	70.00
	Sonic (n=30)	91	1.61	90.00	95.00
	Passive ultrasonic (n=30)	91.8	1.76	90.00	95.00
	Laser (n=30)	99.6	0.71	97.00	100.00
Distal	Conventional needle (n=30)	24.2	11.73	0.00	40.00
	Sonic (n=30)	80	9.34	60.00	94.00
	Passive ultrasonic (n=30)	80.13	6.62	67.00	93.00
	Laser (n=30)	97.68	3.24	89.00	100.00

SD: Standard deviation

TABLE 2. Showed descriptive analysis of each of activation groups at the level of thirds

	Third	n	Mean (%)	±SD
Mesial group				
Conventional needle	Coronal third	10	62.70	4.084
	Middle third	10	62.00	6.182
	Apical	10	43.70	4.373
Sonic	Coronal third	10	92.5	1.96
	Middle third	10	90.6	0.97
	Apical	10	90.1	0.33
Passive ultra sonic	Coronal third	10	93.0	1.69
	Middle third	10	91.1	1.45
	Apical	10	91	1.64
Laser	Coronal third	10	100.0	0.00
	Middle third	10	99.85	0.31
	Apical	10	99.0	0.94
Distal group				
Conventional needle	Coronal third	10	34.8	2.82
	Middle third	10	19.3	13.91
	Apical	10	18.5	7.38
Sonic	Coronal third	10	86.0	5.69
	Middle third	10	83.5	5.64
	Apical	10	70.6	8.09
Passive ultra sonic	Coronal third	10	86.7	4.83
	Middle third	10	78.9	3.25
	Apical	10	74.8	5.12
Laser	Coronal third	10	99.99	0.031
	Middle third	10	99.45	0.78
	Apical	10	93.6	2.32

The results of this study showed that conventional irrigation with needles performed the lowest lateral canal penetrations in all three thirds, on both sides. Other activation groups showed a higher mean percentage of lateral canal penetration, this indicates that the activation methods were more effective in delivering the irrigation into the lateral canals. The results demonstrated also that for all activation groups, the highest percentages of lateral canal penetration were at the coronal third and lowest at the apical third, those findings could be attributed to the possibility of contact of the activation tips with the canal wall, which dampens the process of fluid movement along the root canal wall, particularly at the apical area. For all groups, mesial sides (formed by the #10 reamer) showed higher penetration of the dye into the lateral canals at all thirds than the distal side (formed by the #08 reamer); this means the size of the lateral canal is a limiting factor for the irrigation penetration, and therefore the null hypothesis was rejected.

The results of this study showed that conventional irrigation with needles performed the lowest lateral canal penetrations in all three thirds, on both sides than other activation groups, and this is in line with many previous studies that have proven that typical needle irrigation is ineffective at cleaning isthmuses and lateral canals (27, 28). These results might be attributed to the fact that the typical needle may not create enough pressure to drive the irrigant into simulated lateral canals, particularly those with a tiny diameter. This result is in contrast with Guerreiro-Tanomaru et al. (29). who showed good cleaning and irrigation distribution at the apical area using a 30 gauge needle.

TABLE 3. Showed comparison of mesial and distal sides of each activation group by using T-test

	Mean	n	±SD	T-test	p
Conventional needle					
Mesial	56.1333	30	10.14968	13.169	0.0001
Distal	24.2000	30	11.73383		
Sonic					
Mesial	91.0667	30	1.61743	6.695	0.0001
Distal	80.0333	30	9.34578		
Passive					
Mesial	91.8000	30	1.76947	10.889	0.0001
Distal	80.1333	30	6.62146		
Laser					
Mesial	96.7333	30	3.50304	4.927	0.0001
Distal	93.2000	30	5.15551		

The present study also found no significant difference between passive ultrasonic and sonic at all thirds, mesially and distally, which is consistent with the findings of several previous studies (30, 31). However, several studies have revealed significant differences in sonic and ultrasonic cleaning powers, debris removal from dentinal tubules, and penetration depths of contrast irrigation solution (27–35). The present study's findings could be attributed to the possibility of contact of the ultrasonic stainless-steel tip (25 02) with the canal wall, which dampens the process of fluid movement along the root canal wall, particularly at the apical area (despite its higher frequency), as opposed to the polymer endo activator tip, which does not affect the streaming velocity during contact.

Er, Cr: The YSGG laser activation group showed a highly significant difference with passive ultrasonic in all thirds, mesially and distally, in lateral canal penetrations. This is similar to what was reported by Fidan et al. (36), who determined that the contrast solution penetration into the simulated lateral canals was achieved most effectively by the Er: YAG laser activation technique. Hoshihara et al. (37) reported that the CaOH2 removal rate by laser was significantly higher than passive ultrasonic at all tip insertion depths.

Laser activation irrigation was found to be far more effective than passive ultrasonic irrigation in removing Ca(OH)2 from artificial grooves in the apical section of root canals by de Groot et al. (38), Rasheed et al. (39) discovered that the Er, Cr: YSGG laser activation approach outperforms ultrasonic activation in the elimination of the smear layer during endodontic treatment, particularly in the apical region.

Acoustic streaming and cavitation are frequent occurrences in both Er:YAG laser activation and passive ultrasonic irrigation. With Er: YAG laser activation, the high absorption rate quickly warms the water, causing vaporised bubbles to form and then burst. This causes shock waves and a high fluid flow, which causes photon-induced photoacoustic streaming in front of the tip. With passive ultrasonic irrigation, the acoustic flow surrounding the ultrasonic file is created by the file's vibration. The difference between these processes is thought to be the reason for the different efficacies of laser and ultrasonic activations, also the continuous helicoidal movement throughout all activation time and the more flexible radial tip of laser activation that doesn't affect strongly during contact with canal wall, allowing more irrigation solution to reach all root canal areas and inter-lateral canals.

In this study, the sonic endo activator was less effective than the Er, Cr: YSGG laser at all thirds and on the mesial and distal sides, which agrees with Akcay et al. (40), who concluded the superiority of the Er: YAG laser on the sonic activation in irrigation distribution and removing Ca(OH)2, from artificial grooves and all root canal areas; this could be because the laser's high energy allows for more active movement of irrigation solution than sonic energy (typically, a sonic device operates at 1–8 kHz), also the continuous helicoidal movement throughout all activation time and the more flexible radial tip that doesn't affect strongly during contact with canal wall, allowing more irrigation solution to reach all root canal areas and inter-lateral canals.

The limitation of the present study is that the canal anatomy in clinical cases may be much more complex than the single, wide, and straight canals used in this study. Another limitation is that the irrigation used was normal saline with black ink which differs from sodium hypochlorite in viscosity, surface tension, and flow characteristics which collectively have a direct influence on the solution penetration. Nevertheless, our study may lay a foundation for further studies using teeth with more complex anatomy and a contrast irrigation solution that is mimic the properties of sodium hypochlorite.

CONCLUSION

According to the results of this study, the size of the lateral canal is a restricting factor for all activation methods, with the best results being achieved by Erbium laser (2780 nm); the weakest penetration of lateral canals is by conventional needle, which cannot be used alone for disinfection of complex canal anatomy; good comparable results can be obtained by passive ultrasonic and sonic Endo activator activations.

Disclosures

Conflict of interest: The authors deny any conflict of interest.

Ethics Committee Approval: This study was approved by The Baghdad University, College of Dentistry Ethics Committee (Date: 03/10/2022, Number: 507522).

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