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Efficacy of the Orifice-Level Passive Ultrasonic Activation Technique in Removing Debris from Mandibular Molars: An Ex Vivo Study

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Abstract

Introduction: This study aimed to evaluate the efficacy of the orifice-level passive ultrasonic activation (OL-PUA) technique in removing debris from the mesial root canals of mandibular molars, besides comparing it with other approaches, including manual dynamic agitation (MDA), EndoActivator, and laser-activated irrigation (LAI).

Methods: Ninety mesial roots of mandibular molars were prepared up to 25.06 using the Race rotary system, filled with 3% sodium hypochlorite (NaOCl), and then they were randomly assigned to 5 groups (n = 15) based on the activation protocol: MDA, EndoActivator, OL-PUA, LAI (using a diode laser), and needle irrigation (no activation). Moreover, one group served as the negative control using normal saline as the final irrigant. The roots were decalcified and sectioned into coronal, middle, and apical cross-sections. After histological staining, the remaining debris was assessed with an optical microscope and measured in the canals and isthmuses using histomorphometric analysis. Statistical analyses were performed by using one-way ANOVA and Tukey's HSD post hoc test ($P = 0.05$).

Results: Although less residual debris was observed after OL-PUA/LAI than using the EndoActivator/MDA methods, no significant difference was found between the four activation techniques at any root third ($P > 0.05$). The OL-PUA/LAI group harbored significantly less remaining debris than the needle-irrigated samples at all root thirds ($P < 0.05$). Debris accumulation increased from the coronal to the apical root thirds.

Conclusion: No statistical difference was detected between the four activation techniques in terms of debris-removal performance, and none of them resulted in completely debris-free canals. Orifice-level PUA proved to be a promising approach with significant efficacy in removing debris compared to control groups.

Keywords: Debris; EndoActivator; Laser activation; Root canal irrigation; Ultrasonic.

Introduction

Root canal cleaning and shaping represent indispensable stages in the endodontic procedure, significantly influencing the treatment's success rate and prognosis.[1] Previous studies have highlighted that as much as 35% of root canal walls remain untouched due to complex anatomical features, that is, delta and isthmi.[2] The presence of residual tissue debris after mechanical instrumentation can compromise the cleaning effectiveness of files and lead to potential treatment failures.[3] Consequently, the appropriate utilization of irrigants and disinfectants becomes paramount to ensure efficient cleaning of these challenging-to-reach areas.

Sodium hypochlorite (NaOCl) is the standard dental practice irrigant.[4] The conventional delivery method of NaOCl using needle and syringe irrigation has limitations, as the fluid's reach extends up to 1.5 mm beyond the needle tip.[5] Moreover, the vapor lock effect of side-vented needles restricts the smooth flow of the fluid.[6] To address these challenges, Stojicic et al explored the implementation of various activators, leading to a potential increase in NaOCl efficacy by up to 12 times.[7] Their work suggests that activating NaOCl may enhance its tissue-dissolving properties and antimicrobial potency more effectively

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than simply raising its temperature. Irrigants may be activated through different routes.

Manual dynamic agitation (MDA) is a common and cost-effective NaOCl activation method, achieved through gentle 2- to 3-mm gutta-percha strokes.[8] Air bubbles that form during needle irrigation partially block the canal pathway, hampering the progression of the irrigant toward the apical root third.[9] MDA aids in the effective irrigant circulation to the working length (WL). The EndoActivator is a sonic system incorporating noncutting flexible tips, causing hydrodynamic movements in the disinfectant via "acoustic streaming and cavitation". This action propels the disinfectants into the entire root canal space.[10] Passive ultrasonic activation (PUA) involves the use of a small file or noncutting wire placed within a prepared canal, which is then oscillated ultrasonically to activate the irrigant. It utilizes cavitation and acoustic streaming, leading to disinfectant excitation to mechanically unreachable regions of the root canal.[11] Laser-activated irrigation (LAI) leads to the creation of vapor bubbles within the irrigant. These bubbles subsequently expand and burst, resulting in secondary cavitation effects.[12] At a wavelength of 810 nm, LAI via diode laser has improved clinical outcomes by accelerating periapical healing in necrotic permanent teeth.[13] Moreover, *ex vivo* research has supported the efficacy of LAI with an 810 nm diode laser for the complete removal of *Enterococcus faecalis* from the root canals of deciduous teeth.[14]

Histological examination is effective in studying the efficacy of irrigation activating techniques in removing tissue debris.[15] Histomorphometric analysis is a quantitative method used in histology to study the microscopic structure of tissues. This technique involves the measurement and analysis of various structural parameters of tissues, often using computerized image analysis systems.[16]

Root dentin preservation is critical during the mechanical preparation of the canal system to minimize the risk of root fracture and increase tooth longevity.[17] During PUA, a file or wire must be placed at the canal center as far as down apically so that its free motion allows the detergent to the apical third of the canal.[11] However, despite its efficacy, PUA poses a potential risk in curved canals due to undesirable dentin removal.[18,19] It goes against the fundamentals of conservative endodontics aimed at minimizing root weakening. Even smooth wires have demonstrated similar levels of dentin removal as k-files in the canal apical thirds.[19] Hence, the pursuit of more efficient irrigant activation techniques that reduce excessive dentin removal while effectively removing bacteria and debris takes center stage. This study was conducted to assess the efficacy of the orifice-level passive ultrasonic activation (OL-PUA) technique, and compare it to three common NaOCl activation approaches: MDA, EndoActivator, and LAI, in removing debris from the mesial root canals of mandibular molars. To the best of our knowledge, this is the first study to evaluate the efficacy of the ultrasonic activation technique at the level of canal orifice in minimizing unexpected dentin removal. The null hypothesis indicates no significant difference between these four techniques in removing debris from the root canals.

Materials and Methods

The protocol of this study was approved by the ethics committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.DRC.1398.010). Items of this research were reported in line with the PRILE 2021 guidelines.[20]

Sample Size Calculation

Considering the type one error at $\alpha = 0.05$, the type two error at $\beta = 0.2$ (80% power), and the findings obtained by Llena et al,[21] a sample size of 90 was determined by using PASS 11 software (NCSS, LLC. Kaysville, Utah, USA).

Sample Selection

Ninety freshly extracted permanent mandibular molars with healthy roots and complete apices, with no sign of root canal resorption, caries, or calcification, were selected for this study. All included teeth were extracted from participants within the age range of 25 to 45 years, for reasons unrelated to this research. Soft tissue, bone remnants and calculus were mechanically cleaned from the root surfaces by using a periodontal scaler. Radiographs were taken of each tooth, and the degree of root canal curvature was measured by using the Schneider method.[22] Only teeth with root canal curvature ranging between 15 and 45 degrees were included in the study. The teeth were stored in 2.5% NaOCl (Morvabon, Tabriz, Iran) for 24 hours, followed by normal saline (NS) until use.

Preparation Protocol

The molars were hemisected by using a fissure diamond bur (DiaTessin, Switzerland), and the coronal portion of the teeth was trimmed to achieve a consistent length of 19 mm. The teeth were placed in an endodontic training model (VDW GmbH Bayerwaldsrt 15. 81737, Munich, Germany), and an access cavity was prepared for each tooth. In each mesial root, two size 10 K-files (Mani Inc, Tochigi, Japan) were inserted in mesiobuccal and mesiolingual canals. The canals were negotiated until the file tip was barely visible at the apical foramen using a dental operating microscope (Carl Zeiss Meditec AG, Oberkochen, Germany). The WL was determined by withdrawing the file 1 mm from that point.

The apices of all teeth were sealed with wax to achieve a closed system that simulates clinical situations. The mesial root canals were prepared by using a manual K-file up to size 15. Then, the Race rotary system (FKG Dentaire SA, CH-2304 La Chaux-de-Fonds, Switzerland) on the VDW

RECIPROC rotary motor (silver model: TR30RAM120) was used in the following order: orifice opener, 15.02, 20.02, 20.04, 25.04, and 25.06. Files were used passively, with a maximum of three pecking motions until reaching the established WL. After using each file, the canals were irrigated with 2 mL of NS using a 27-gauge side-vented needle. The needle tip was placed at a distance no further than 2 mm from the WL without binding to canal walls and then moved back and forth.[23] A total of 10 mL of NS was used during the preparation of the teeth.

The teeth were labelled with numbers between 1 and 90, and the numbers were entered into an Excel spreadsheet. Then, random values were generated for each number, and based on that, the teeth were randomly assigned into five experimental groups and one control group. A plastic tube was fixed on the coronal part of the specimens as an irrigant reservoir. For the final irrigation, the canal, pulp chamber, and plastic reservoir were filled with 2 mL of 3% NaOCl (Morvabon, Tabriz, Iran) in the experimental groups. The six study groups were as follows:

- Group A: MDA using a size 25 well-fitting gutta-percha master cone, inserted 1 mm short of the WL. Irrigant agitation was performed for 1 minute at a frequency of 100 push-pull motions/minute (n = 15).[24]
- Group B: Activation via EndoActivator (Maillefer, Switzerland). The EndoActivator system was used according to the manufacturer's recommendations. Irrigant activation was performed for 1 minute with a 25.04 noncutting polymer tip, placed 1 mm short of the WL at 10 000 cycles/minute (n = 15).[25]
- Group C: OL-PUA using an ultrasonic device (Ultramint pro, Eighteeth, Changzhou, China) and the E4 tip for 1 minute at 80 mJ and 30 kHz.[26] The ultrasonic tip was placed in the pulp chamber at the orifice level of the canal and then activated in 3 cycles of 20 seconds each (n = 15).
- Group D: Activation using a diode laser (Elexxion IEC60825-1: 2001) with an 810 nm wavelength and 200 µm diameter fiber size (pulse output of 4 watts, average power of 1.36 watts, 20 Hz frequency, µs pulse duration) placed 1 mm short of the WL with spiral motion and speed of 2 mm/s for 20 seconds. Then, the NaOCl was left in the canal for up to 20 seconds (n = 15).[13]
- Group E: Needle irrigation (positive control); after filling the canal and pulp chamber with NaOCl, the samples were left undisturbed for 1 minute without any intracanal activation of the irrigant (n = 15).
- Group F: Negative control; final irrigation was done by using 2 mL of NS after the use of a 25.06 rotary file (n = 15).

After completing the irrigation and activation protocols, all teeth were rinsed first with 5 mL of 17% EDTA solution (MASTER-DENT, Monroe, NC, USA) for 1 minute to remove the smear layer and then 5 mL of distilled water for 1 minute using a 27-gauge side-vented needle.[23]

Microscopic Evaluation

All roots were placed in 10% formalin (by volume) for 2 days. Then, the teeth were washed and placed in 10% formic acid for decalcification for a minimum of 4 weeks to 2 months to reach suitable softness for cutting. Each root was then sent to the pathology laboratory to prepare six-micron-thick sections. For each root, 3 sections were randomly chosen at a 2, 4, and 6-mm distance from the anatomical apex, representing the apical, middle, and coronal root thirds, respectively. Slides were prepared from each root third and stained with hematoxylin and eosin, then subjected to microscopic imaging (Olympus-SCX90, Japan) at a magnification of 40x (Figure 1). The root canals and if present, the isthmus between the two canals, were outlined. The areas occupied by stained debris within these regions were determined. To ensure impartiality, this procedure was executed by a blinded experienced practitioner who had no involvement in the canal preparation and irrigation steps.

Statistical Analysis

The percentage of the remaining debris was evaluated by using the Iranian histomorphometric analysis software (IHMMA, version 1, SBMU, Iran). All data pertaining to

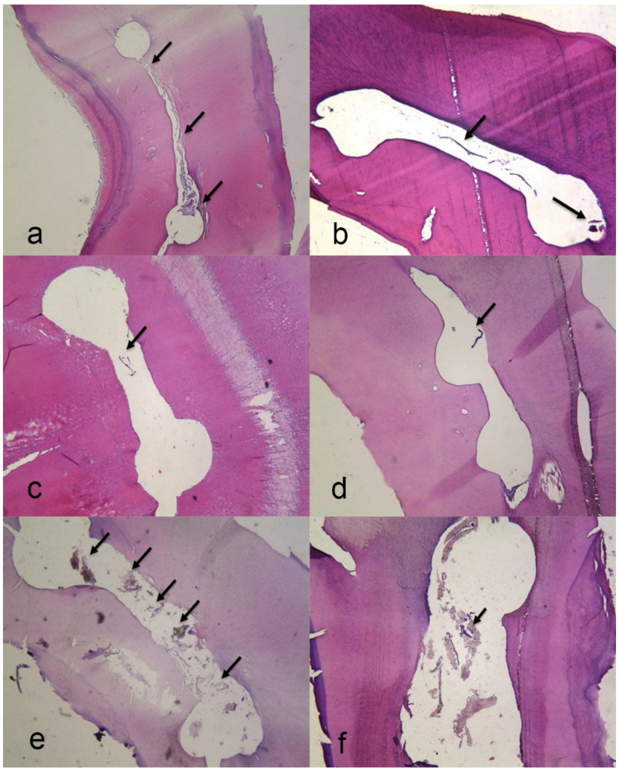

Figure 1. Light Microscope Images Taken of the Middle Third of the Roots at 40x Magnification; a: Manual dynamic agitation, b: EndoActivator, c: Passive ultrasonic activation, d: Laser-activated irrigation, e: Needle irrigation, f: Negative control

each group were recorded in a data sheet and subjected to comparison using the SPSS Version 20 software (IBM Corp. Armonk, NY, USA). The mean percentage of the area occupied by debris and its standard error were reported for each root third.[16]

A Kolmogorov-Smirnov test was used to evaluate the normality of data distribution in the studied groups. The Levene test was used to compare the variances of the groups. Due to the normality of data distribution and equality of variances, comparisons between the groups were performed by using one-way ANOVA. Tukey's HSD (honestly significant difference) post hoc test was performed to compare the mean percentage of debris in group pairs. To compare the data in three root thirds, repeated measures ANOVA and the Bonferroni method were employed after the use of Mauchly's test of sphericity. The level of statistical significance was set at $P<0.05$.

Results

Total Root Samples

Figure 2 illustrates the mean percentage of the remaining debris in the study groups, categorized by root thirds. The slightest remaining quantity of debris belonged to samples subjected to OL-PUA and LAI. OL-PUA left 2.3% debris in the coronal root third, followed by LAI with 2.9% debris. In the mid-root, 7.3% and 8.1% of the debris was left behind after OL-PUA and LAI, respectively. The apical third was occupied by 10.9% debris after OL-PUA and 12% after LAI. However, the difference between the four activation groups was not statistically significant at any of the root thirds (Table 1). Four intervention groups contained significantly less remaining debris compared to the negative control at each of the root thirds ($P<0.05$). Compared to the needle irrigation, LAI left significantly less debris at the coronal ($P=0.002$), middle ($P=0.032$), and apical ($P=0.020$) root thirds (Table 1). Correspondingly, less debris was detected in the OL-PUA group than in the needle irrigation at the coronal ($P=0.001$), middle ($P=0.017$), and apical ($P=0.011$) root thirds.

Overall, the mean percentage of the remaining debris increased in a corono-apical direction inside the roots (Figure 2). In the negative control group, however, this trend was not statistically significant between either of the two root thirds (Table 2). When comparing the coronal with apical root thirds, a significant difference in debris mass was observed by using MDA ($P=0.027$), EndoActivator ($P=0.003$), OL-PUA ($P=0.030$), LAI ($P=0.021$), and needle irrigation ($P<0.001$), with apical debris outnumbering the coronal debris.

Roots with Isthmus

In the coronal third, OL-PUA and LAI left 4.03% and 5.21% as the minimum percentage of debris, respectively (Figure 3). In the middle third, 10.11% debris was left after LAI, followed by 11.26% debris after MDA. In the apical third, EndoActivator left 16.18% as the slightest remaining debris, followed by the OL-PUA group with 16.23% debris. Nevertheless, no significant difference was detected between the intervention groups at any region of the roots ($P>0.05$). OL-PUA showed significantly less debris ($P=0.029$) than the positive control in the coronal third of the roots, with a mean difference of 11.63 (Table 3). Compared to the negative control, significant differences were detected with all activation methods in all root thirds except MDA in the coronal and apical thirds and EndoActivator in the coronal third (Table 3).

Discussion

Tissue debris accumulation during root canal preparation harbors microorganisms[27] and inhibits irrigating solutions from exerting effect.[28] Hence, it jeopardizes the treatment outcome. In the present study, we investigated the cleaning efficacy of four NaOCl activation methods (MDA, EndoActivator, OL-PUA, and LAI) by measuring the percentage of the remaining debris residing on the

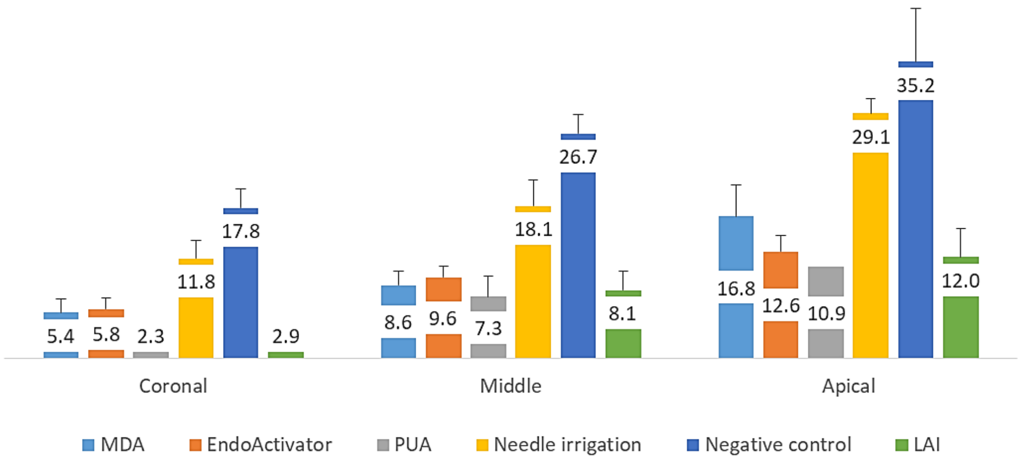

Figure 2. Mean Percentage of the Remaining Debris After Activation With Different Methods in Total Root Samples; MDA: manual dynamic agitation, PUA: passive ultrasonic activation, LAI: laser-activated irrigation

Table 1. Intergroup Comparison of the Mean Percentage of Canal Areas Occupied by Debris at Different Root Thirds (Mean Difference ± Standard Error)

			Coronal	Middle	Apical
Manual agitation	EndoActivator		-0.43 ± 2.03	-0.96 ± 2.89	4.17 ± 4.68
		P	1.000	0.999	0.947
	Ultrasonic activation		3.05 ± 2.03	1.31 ± 2.89	5.93 ± 4.68
		P	0.667	0.997	0.802
	Needle irrigation		-6.44 ± 2.27	-9.41 ± 3.23	-12.23 ± 5.24
		P	0.064	0.052	0.194
	Negative control		-12.43 ± 2.27	-18.02 ± 3.23	-18.39 ± 5.24
		P	0.000*	0.000*	0.010*
	Laser activation		2.54 ± 2.03	0.58 ± 2.89	4.82 ± 4.68
		P	0.810	1.000	0.907
EndoActivator	Ultrasonic activation		3.48 ± 2.03	2.27 ± 2.89	1.75 ± 4.68
		P	0.530	0.969	0.999
	Needle irrigation		-6.01 ± 2.27	-8.45 ± 3.23	-16.41 ± 5.24
		P	0.101	0.106	0.029*
	Negative control		-12.00 ± 2.27	-17.06 ± 3.23	-22.57 ± 5.24
		P	0.000*	0.000*	0.001*
	Laser activation		2.98 ± 2.03	1.55 ± 2.89	0.64 ± 4.68
		P	0.688	0.994	1.000
Ultrasonic activation	Needle irrigation		-9.49 ± 2.27	-10.72 ± 3.23	-18.17 ± 5.24
		P	0.001*	0.017*	0.011*
	Negative control		-15.48 ± 2.27	-19.33 ± 3.23	-24.32 ± 5.24
		P	0.000*	0.000*	0.000*
	Laser activation		-0.50 ± 2.03	-0.72 ± 2.89	-1.11 ± 4.68
		P	1.000	1.000	1.000
Needle irrigation	Negative control		-5.99 ± 2.49	-8.60 ± 3.53	-6.15 ± 5.74
		P	0.169	0.159	0.891
	Laser activation		8.99 ± 2.27	10.00 ± 3.23	17.05 ± 5.24
		P	0.002*	0.032*	0.020*
Negative control	Laser activation		14.98 ± 2.27	18.61 ± 3.23	23.21 ± 5.24
		P	0.000*	0.000*	0.000*

*Significant at the 0.05 level.

canal walls of the mesial roots of mandibular molars. According to our findings, while each intervention group exerted higher cleaning efficacy than the control groups, the difference between activation methods was not statistically significant at any root third. Hence, the null hypothesis was accepted.

We selected the mesial roots of the mandibular molars due to their mechanically inaccessible areas.[29] We prepared the canals minimally to inspect the efficacy of the activators more precisely. While NaOCl is considered the preferred irrigating solution,[4] we utilized NS irrigation during the preparation steps and reserved NaOCl as the final irrigant. This choice was deliberate as our main focus was to assess the effectiveness of activation methods in removing debris, rather than targeting biofilm. We opted to use the diode laser due to its affordability and ease of operation. Additionally, minimal absorption by dental calcified tissues and strong absorption in water makes it a safe and selective activation option.[30] We undertook histological analysis via optical microscopy since it allows for the accurate visualization of debris in the isthmus and different areas of the canal in cross-section.[15]

PUA presents a potential hazard in curved root canals by inadvertently removing dentin.[18,19] Therefore, as a novel approach, the ultrasonic tip was inserted at the orifice level in this study to maintain safety by preventing excess dentin removal. Other researchers have explored alternative means to address this concern. Some studies have investigated the activation efficacy of lasers at the canal entrance, demonstrating promising debris removal without detrimental effects on the canal walls.[31,32] Additionally, a recently introduced ultrasonic activation device functions from above the pulp chamber, showing proficiency in eliminating biofilm from simulated isthmus models and highlighting the potential of minimally invasive activation techniques.[33]

According to our results, the accumulated debris mass increased considerably from the coronal third of the canal to the apex, which aligns with previous findings.[34] Aside from natural canal tapering, the physiological tubular sclerosis could be a contributing factor.[35]

It is worth noting that less than half of the samples in our study contained an isthmus, which limits our ability to draw definitive conclusions regarding the efficacy of activation methods in the isthmus area. We found no significant difference between the activation methods in these samples, as supported by previous studies.[36,37] Swimberghe et al, on the other hand, showed that LAI is significantly more efficacious than the EndoActivator/PUA.[32] The accumulated debris mass in roots containing an isthmus followed an increasing trend corono-apically, which is explained by the fact that isthmus occurrences are more prevalent in the middle and apical canal thirds.[29]

Table 2. Two by Two Comparisons at Different Root Thirds for Each Intervention Group (Mean Difference ± Standard Error)

			Mean Difference ± Standard Error	*P*
Manual agitation	Coronal	Middle	-3.24 ± 1.64	0.204
	Coronal	Apical	-11.41 ± 3.76	0.027*
	Middle	Apical	-8.17 ± 2.82	0.035*
EndoActivator	Coronal	Middle	-3.77 ± 1.34	0.042*
	Coronal	Apical	-6.80 ± 1.63	0.003*
	Middle	Apical	-3.03 ± 1.52	0.199
Ultrasonic activation	Coronal	Middle	-4.98 ± 1.95	0.070
	Coronal	Apical	-8.53 ± 2.87	0.030*
	Middle	Apical	-3.54 ± 1.55	0.116
Needle irrigation	Coronal	Middle	-6.21 ± 1.62	0.012*
	Coronal	Apical	-17.20 ± 1.45	0.000*
	Middle	Apical	-10.99 ± 2.00	0.001*
Negative control	Coronal	Middle	-8.83 ± 3.32	0.079
	Coronal	Apical	-17.37 ± 7.96	0.171
	Middle	Apical	-8.54 ± 5.74	0.514
Laser activation	Coronal	Middle	-5.20 ± 2.00	0.063
	Coronal	Apical	-9.14 ± 2.89	0.021*
	Middle	Apical	-3.94 ± 2.51	0.418

*Significant at the 0.05 level.

We discovered no significant difference between activation methods at any root third. However, NaOCl activation was more effective in reducing debris mass compared to needle irrigation. Our findings align with the results reported by Deleu et al, who found no significant difference between PUA and MDA, while both methods surpassed conventional irrigation.[24] Other studies reported the same result for PUA and EndoActivator.[34,36] Moreover, only OL-PUA and LAI could significantly remove more debris than needle irrigation in our study, as supported by the literature.[31,38-40]

According to our findings, OL-PUA statistically outperformed needle irrigation at all root thirds and exerted comparable efficacy compared to other activation techniques. This fact may set up a firm basis for future *in vitro* and clinical research to determine the depth at which PUA exhibits ideal efficacy in debris, smear layer, and biofilm removal while minimizing the destruction of the inner canal walls. Further clinical trials are also required to assess and verify the performance of OL-PUA on the healing of periapical lesions. One potential concern with employing this technique is that OL-PUA delivers intermittent flushes of NaOCl that may reduce the penetration of irrigants into canal intricacies. When in contact with tissues, the chlorine component in NaOCl that is responsible for tissue dissolution undergoes instability and is inactivated eventually. To address this issue,

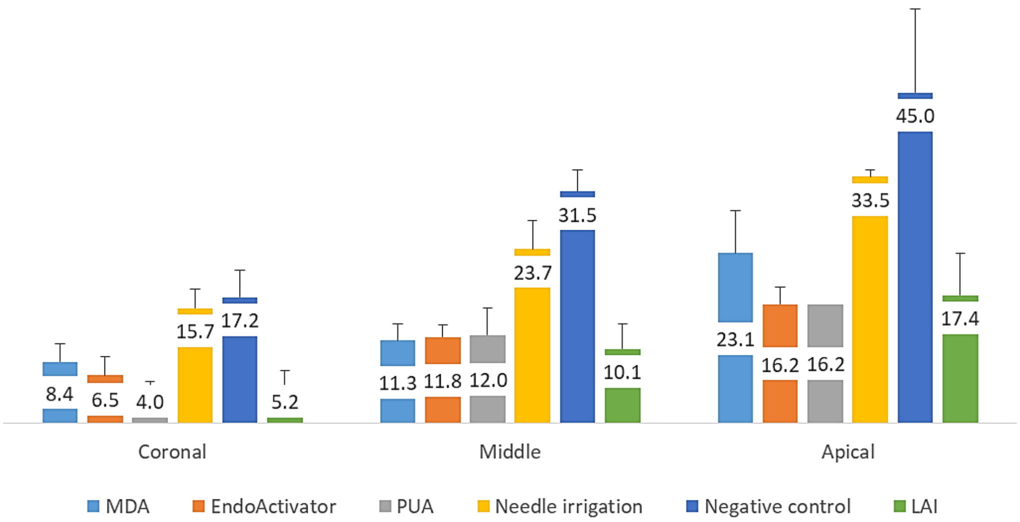

Figure 3. Mean Percentage of the Remaining Debris After Activation With Different Methods in Root Samples Containing an Isthmus; MDA: manual dynamic agitation, PUA: passive ultrasonic activation, LAI: laser-activated irrigation

Table 3. Intergroup Comparison of the Mean Percentage of Canal Areas Occupied by Debris at Different Root Thirds in Roots Containing an Isthmus (Mean Difference ± Standard Error)

			Coronal	Middle	Apical
Needle irrigation (n = 5)	Manual agitation (n = 7)		7.28 ± 3.59	12.42 ± 4.65	10.36 ± 8.48
		P	0.349	0.108	0.824
	EndoActivator (n = 7)		9.11 ± 3.69	11.92 ± 4.78	17.32 ± 8.71
		P	0.161	0.154	0.369
	Ultrasonic activation (n = 7)		11.63 ± 3.59	11.65 ± 4.65	17.27 ± 8.48
		P	0.029*	0.151	0.344
	Negative control (n = 5)		-1.50 ± 3.98	-7.84 ± 5.16	-11.45 ± 9.41
		P	0.999	0.655	0.826
	Laser activation (n = 7)		10.45 ± 3.59	13.57 ± 4.65	16.09 ± 8.48
		P	0.064	0.063	0.421
Negative control (n = 5)	Manual agitation (n = 7)		8.79 ± 3.59	20.26 ± 4.65	21.81 ± 8.48
		P	0.169	0.001*	0.132
	EndoActivator (n = 7)		10.62 ± 3.69	19.76 ± 4.78	28.78 ± 8.71
		P	0.069	0.003*	0.025*
	Ultrasonic activation (n = 7)		13.13 ± 3.59	19.49 ± 4.65	28.72 ± 8.48
		P	0.010*	0.002*	0.020*
	Laser activation (n = 7)		11.95 ± 3.59	21.41 ± 4.65	27.54 ± 8.48
		P	0.023*	0.001*	0.029*

*Significant at the 0.05 level.

continuous renewal of the irrigant could be beneficial.[8] Hence, it is advisable to employ the continuous ultrasonic irrigation activation technique instead of PUA.[41] This technique has demonstrated promising outcomes in human teeth with vital/necrotic pulps.[42,43]

Based on our results, with no significant difference with OL-PUA, LAI offered a substantially cleaner canal than needle irrigation in all root thirds. De Groot et al. studied the effect of PUA and erbium-doped yttrium aluminum garnet (Er:YAG) LAI on dentin debris.[44] They concluded that LAI demonstrated significantly better performance in removing debris from the apical third of the roots compared to PUA/MDA. The discrepancy between our findings and those of De Groot et al. might be attributed to the superiority of Er:YAG over diode laser/ultrasonic activation.[24,45]

Heterogeneous findings about the efficacy of activation techniques have been reported in the literature. Our results indicated that PUA was significantly more effective than needle irrigation in every section of the canal. However, Wigler et al showed that the difference between the two methods was not statistically significant.[46] Opposite to our study, no significant difference was observed between ultrasonic activation, EndoActivator, and needle irrigation in another study.[25] Plotino et al concluded that PUA was significantly more effective than EndoActivator in coronal and middle root thirds; however, no significant difference was observed in the apical third.[23] These inconsistencies can be explained by the distinct methodological aspects of the studies, that is, final canal preparation size, NaOCl concentration, and subtle variations in activation specifications, underlying the need for a standardized protocol in this field. Furthermore, the choice of activation may depend on various factors, namely type of the laser used, the presence of clinical symptoms, and clinician expertise. Therefore, further well-designed research in this area is warranted to determine the optimal activation method for root canal cleaning with the least adverse effects on sound tooth structure.

Our research comes with a few limitations. First, we focused on the mesial roots of mandibular molars, so our findings may not be directly applicable to other teeth or root canal anatomies. Moreover, we used light microscopy to measure the remaining debris inside the canals. Further research should be performed by duplicating the novel OL-PUA technique as used in this study while employing more advanced micro-CT devices to precisely inspect the remnant debris on the canal walls. Additionally, the use of more powerful lasers and the activation of EDTA as a chelating agent are recommended as prospective directions for authors. A positive aspect of our study is that we performed PUA specifically at the orifice level to maximize the preservation of the root dentin. Interestingly, this approach resulted in noticeable cleaning effectiveness.

Conclusion

All limitations considered, no significant difference was observed between the four activation methods regarding debris removal at coronal, middle, and apical root thirds. All activation methods effectively reduced the remaining debris mass; however, none of them sustained root canal walls completely devoid of debris. With no adverse effects on the intraradicular dentin, PUA performed at the orifice level showed to be a promising approach exerting significant efficacy in removing debris compared to control groups.

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Data Availability Statement

All data pertaining to this work is available and can be obtained by contacting the corresponding author upon reasonable request.

Ethical Approval

The protocol of this study was approved by the ethics committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.DRC.1398.010). All procedures performed in this study were in accordance with the 1964 Helsinki Declaration and its later amendments.

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