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Review article

IMPACT OF THE PASSIVE/ACTIVE ULTRASONIC ACTIVATION ON THE ENDODONTIC IRRIGANTS EFFECTIVENESS - A REVIEW

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ABSTRACT:

Introduction: various irrigation devices and chemical solutions are being developed and improved nowadays for better penetration deep into the complex root canal system. Activation of irrigating solutions enhances the solution effectiveness. Evidence in the literature suggests that ultrasonic irrigation is much more effective in this respect than syringe irrigation alone.

Passive ultrasonic irrigation (PUI) and/or ultrasonically activated irrigation (UAI): nowadays, the two terms, PUI and UAI, are interchangeable in the literature and represent the same technique. Literature data have shown that combining ultrasonically activated NaOCl with EDTA results in significantly greater removal of the smear layer.

Conclusion: the use of ultrasonic activation of the irrigating solution after root canal preparation significantly improves the removal of debris from hard-to-reach areas such as isthmuses, lateral canals and the apical delta.

Keywords: irrigants, active ultrasound activation, passive ultrasound activation, ultrasound, smear layer,

INTRODUCTION:

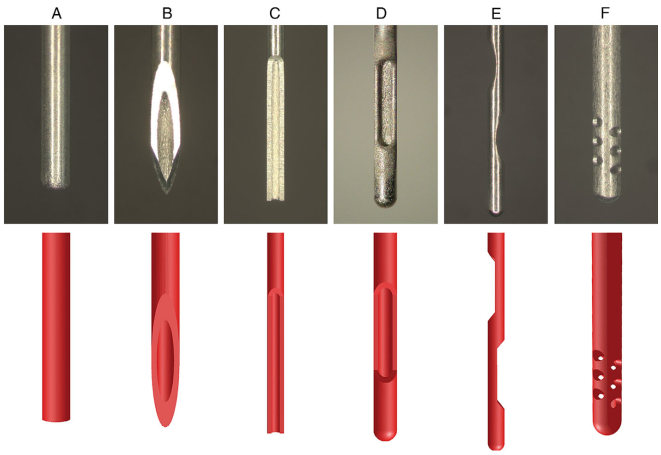
The success of root canal treatment depends on the destruction and elimination of microorganisms from the root canal system and the prevention of reinfection. For achieving these goals, the manual and rotary shaping of the root canal is performed under continuous irrigation in order to remove the inflamed and necrotic tissue, microorganisms and their by-products. Thanks to micro-computed tomography, modern studies have shown that large areas of the main root canal remain unchanged by endodontic instrumentation [1], emphasizing the importance of chemical cleaning and disinfection in all root canal areas. However, there is no single irrigating solution that meets all the requirements for good irrigation. There are combinations of two or more irrigating solutions that ensure safe and effective irrigation.

Clinical studies have shown that the classical method of syringe irrigation is insufficiently effective because of the various isthmuses, lateral canals and especially in the apical delta [2]. Therefore, various irrigation devices and chemical solutions are being developed and improved nowadays for better penetration deep into the complex root canal system.

Ultrasonic activation of irrigating solutions:

Irrigating solutions that have been additionally activated by sound, ultrasound, or laser remove debris and dental pulp remnants and disinfect the root canal system more effectively. Irrigating solutions clean precisely these hard-to-reach spaces. Unfortunately, syringe irrigation cannot fulfil the desired goals for maximum disinfection of the root canal space. Shen et al. [3] have described the correlation between the needle tip design and the velocity of irrigant outflow. Open-ended needles allow faster irrigation than side-vented needles (fig. 1).

Fig. 1. Different types of open-ended needles.



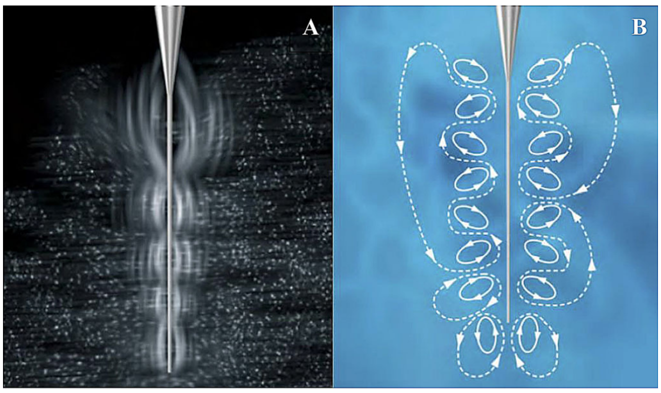
Open-ended needles irrigate most effectively the adjacent 1-2 mm. Better cleaning of the apical part is possible when the needle is close to the apical foramen; however, there is a risk of extrusion of the solution. The higher pressure generated during the solution outflow from the needle implies better decontamination of the root canal walls. The three parameters, fluidity of the solution, the velocity of the irrigant flow and the pressure applied to the canal walls, impact the cleaning performance of irrigation. Unfortunately, recent studies have confirmed that areas such as the isthmuses, lateral canals, and apical delta remain unclean with the syringe irrigation technique [4].

Activation of irrigating solutions enhances better cleaning of the root canal system. Studies by Dutner et al. have found that only in 50% of the cases a specialized device was used to activate the solutions. In one of the studied groups, ultrasonic activation was applied in 48% and sound activation in 34% of the cases [5].

Richman [6] was the first who applied ultrasound in endodontics. He used the Cavitron® ultrasound device. In numerous articles in the endodontic literature from 1976 to 1985, Martin and Cunningham described the use of ultrasound as a means for shaping and disinfection of root canals [7].

Martin and Cunningham [8] explain the success of ultrasonic instrumentation with the interaction between ultrasonic energy and the irrigating solution. They call this interaction a "synergistic system." The irrigating solution increases its biochemical activity under the influence of ultrasonic energy. The authors define cavitation and acoustic flow as the primary effects of ultrasound. In a dry medium, cavitation occurs when ultrasonic energy generates air bubbles, which collapse when reaching a surface. This collapse creates a vacuum effect that mechanically reduces irregularities on the root canal walls and destroys microorganisms. When the ultrasound is directed into a liquid medium, the ultrasonic wave creates bubbles that grow larger and larger until they collapse into a powerful explosion. This effect, generated by the oscillating ultrasonic instruments, powerfully activates the solution in the root canals and is defined as resonant or stable cavitation. The cavitation effect is also combined with the mechanical energy of the ultrasound-induced acoustic waves, thereby increasing the cleaning and disinfecting ability. The explosion of the bubbles generates waves that repeat at a frequency of 25,000-30,000 times per second (25-30 kHz). The explosion itself generates a temperature of up to 5,000°C and a pressure of up to 500 atm. The waves generated by the explosion travel at velocities exceeding 500 mph and the resulting flow of waves is called acoustic (figure 2) [9].

Fig. 2. Photo (A) and schematic depiction (B) of ultrasound acoustic streaming.



The acoustic flow can also be obtained from an ultra-high oscillation of a tip or a file placed in a liquid, as the solution has to be constantly renovated in order for the maximum amount of new pure solution to be in contact with the root canal walls. This increases the efficiency of the ultrasonic explosion, which reaches the irregularities on the root canal walls and surfaces that are difficult to be cleaned when using inactivated solutions [4]. To get into the essence of the mechanism of ultrasonic instrumentation, Ahmad et al. [10] studied the phenomenon of cavitation and the acoustic flow in the root canal space. The authors performed the study using a photometrically sensitive device. The device detected the light obtained from the powerful collapse of the bubbles. For this purpose, rectangular containers filled with methylene blue dye, in which polystyrene spheres were immersed, were used. The latter were illuminated so that the resultant light was captured by the acoustic flow of the samples, and the device could determine whether an acoustic flow was present. Forty extracted human front teeth were used, which were divided into four groups. The teeth were instrumented with hand files or ultrasonic files (Cavi-Endo®), using 2.5% NaOCl or distilled water for irrigation. The teeth were split longitudinally, and the presence of a smear layer on the root canal walls was assessed by conventional electronic microscopy (SEM). The authors have concluded that the resulting acoustic flow is much more important than cavitation in removing the smear layer and that ultrasonic instrumentation does not produce enough acoustic flow to clean the root canal.

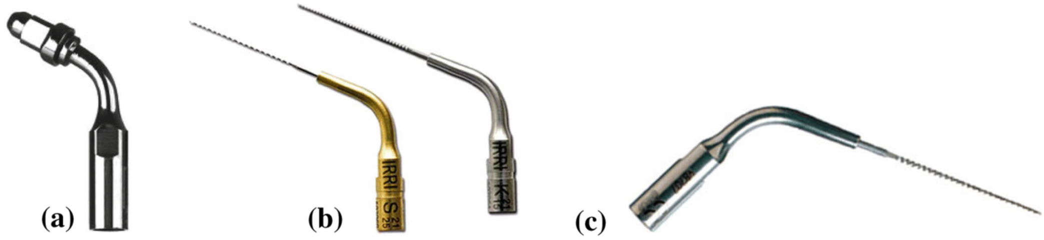
In later studies, Ahmad et al. [11] found that the generation of acoustic flow can occur in both larger and narrower spaces. They examined the high-frequency flow by using small ultrasonic files, pre-curving the used file in the presence of a curve in the root canal. The light contact of the file with the root canal wall did not completely interrupt the acoustic flow, while the tight contact immediately interrupted the generation of acoustic flow.

Passive ultrasonic irrigation (PUI) and/or ultrasonically activated irrigation (UAI)

The terminology used for the activation of irrigating solutions can be quite confusing [4]. Weller et al. [12] compared the effectiveness of ultrasound as a primary method of instrumentation and as an adjunct to manual instrumentation. The authors have concluded that ultrasonic file instrumentation is not an alternative to manual instrumentation but can be used as an additional method to increase the efficiency of removing debris and the smear layer. In later studies, the same authors [13] considered ultrasonic instrumentation as a more passive method, which is used after manual instrumentation, does not enlarge or change the root canal wall in any way. As a result of these claims, the term "passive ultrasonic irrigation (PUI)" has emerged, given that there is no active, targeted removal of dentin from the root canal wall. However, it should be noted that the oscillating ultrasonic file is in contact with the dentin of the root canal. Boutsioukis et al. [14] introduced the term "ultrasonically activated irrigation (UAI)" in cases where the use of ultrasound alone or as a complementary method alters and affects the dentin of the root canal. Nowadays, the two terms, PUI and UAI, are interchangeable in the literature and represent the same technique [4]. Many studies have been performed to determine the ability of PUI/UAI to remove pulp tissue, debris, bacteria, biofilm, smear layer, calcium hydroxide and other medications. They compare the use of different sizes of ultrasonic files in different sizes of enlarged root canals and the use of smooth ultrasonic files with that of grooved, filing ultrasonic instruments.

In most cases, the PUI/UAI treatment involves the use of endodontic files placed on a tip, e.g. Endochuck 120°, 90°, 180° (EMS, Switzerland), from which the ultrasonic energy is obtained (Fig. 3 a.). The ultrasonic files are have different sizes - # 15 or # 20 (Fig. 3 b, c.). The depth of placement of the ultrasonic file in the root canal and its mode of movement has also been studied.

Fig. 3. Different holders for ultrasonic tips.



This steel tip serves as an adapter on which various endodontic files can be mounted, such as K-files, H-files, U-files, spreaders or files with a special design made especially for ultrasonic instrumentation. The adapters can be without a curve, e.g. Endochuck 180° (EMS, *Switzerland*), with a curve at an angle of 90° for more comfortable work in the distal part of the dentition and at an angle of 120° for work in the anterior areas. The Irrisafe™ (Satelec Acteon, *France*) presents different sizes and lengths of the instruments – # 20 and # 25 (according to the ISO), lengths 21 and 25 mm. The ultrasound instrument itself has a built-in channel through which the irrigating solution can be delivered to the root canal (Fig. 3 b.). The Satelec Sonofile K-File (Dentsply Sirona, *USA*) tips are similar to the Irrisafe™ (Satelec Acteon, *France*) but without a longitudinal channel in the irrigation file (Fig. 3 c.).

Removal of debris and the smear layer from the root canal by ultrasonic irrigation

The ability of PUI/UAI to remove pulp tissue, debris and the smear layer has been extensively studied. Evidence in the literature suggests that ultrasonic irrigation is much more effective in this respect than syringe irrigation alone. Goodman et al. [15] were the first authors who studied the ability of ultrasonic energy to remove the smear layer. They demonstrated that the application of PUI/UAI with sodium hypochlorite (NaOCl) solution for 3 minutes per root canal significantly improved the cleanliness of isthmuses in the medial roots of the lower molars, as the *in vitro* study was performed at levels 1 and 3 mm from the apical end of the root canal. Metzler and Montgomery [16] obtained similar results using PUI/UAI for 2 minutes. Our studies have confirmed the higher efficiency of removing the smear layer when applying ultrasonically activated 2% NaOCl solution [17]. The obtained scanograms illustrate the results of the middle and apical parts of the root canals (Fig. 4, 5).

Fig. 4. Scanogram of dentin from the middle third of the root canal, irrigated with inactivated 2% NaOCl solution (magnification x 2500)

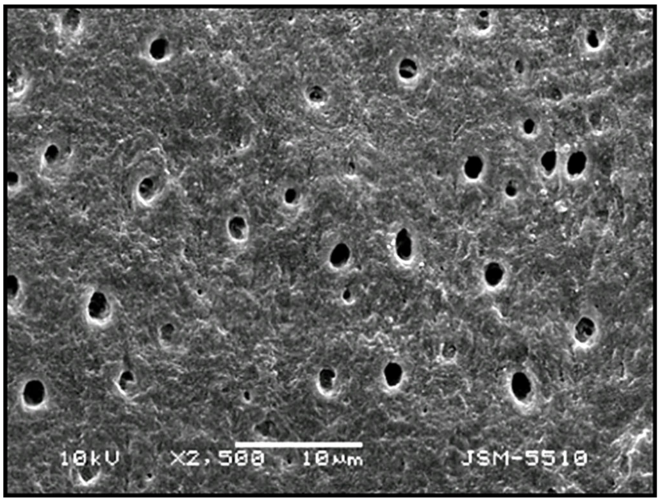
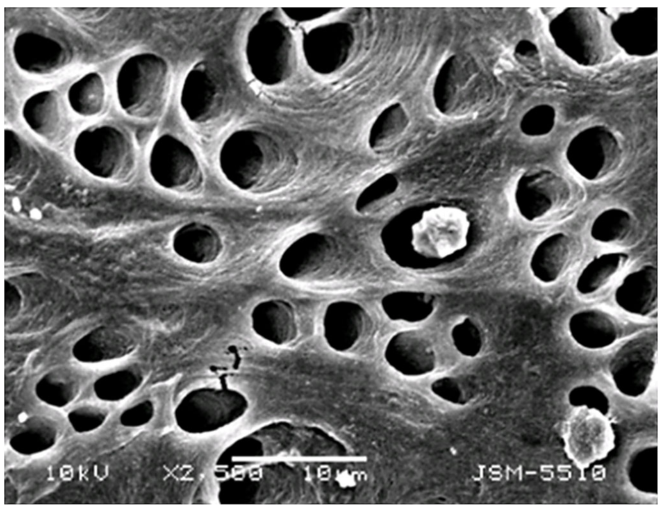
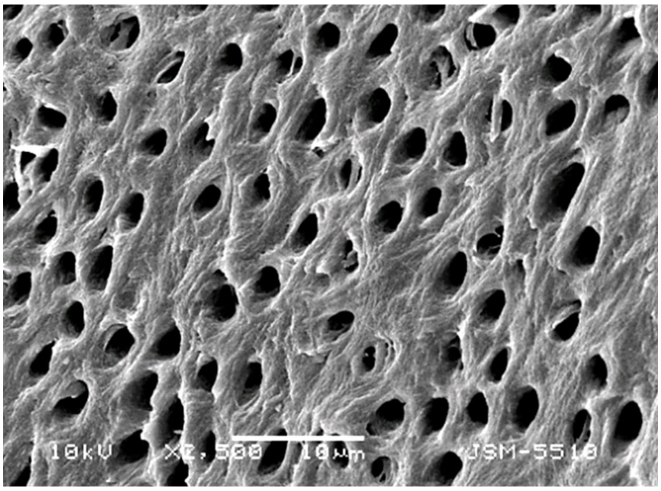


Fig. 5. Scanogram of dentin from the apical third of the root canal, irrigated with activated 2% NaOCl solution (magnification x 2500)



Cameron [18] has reported less debris and pulp tissue when using PUI/UAI in sequential irrigation with ethylenediaminetetraacetic acid (EDTA) and NaOCl for 1.5 minutes per canal. Literature data have shown that combining NaOCl with EDTA results in significantly greater removal of the smear layer [19]. As the concentration of NaOCl increases, so does its toxicity. Sequential application of ultrasonically activated solutions of NaOCl and EDTA removes the smear layer sufficiently effectively even at lower concentrations of NaOCl [20]. Our studies have shown the effectiveness of removing the smear layer when applying ultrasonically activated solutions of 2% NaOCl and 15% EDTA (Fig. 6) [17].

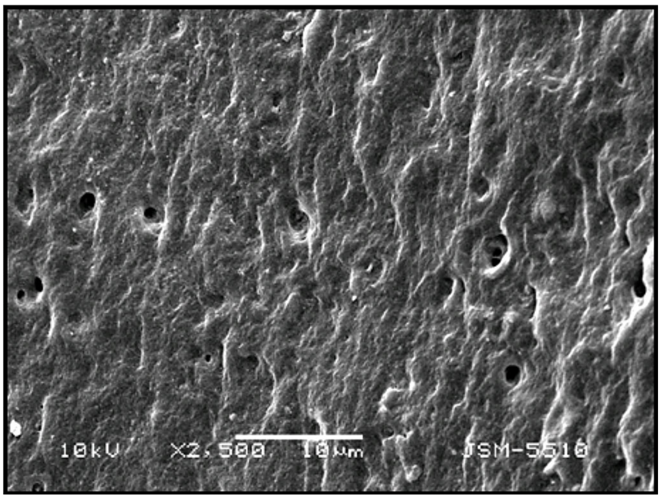
Fig. 6. Scanogram of dentin from the coronary third of the root canal, irrigated with activated 2% NaOCl and 15% EDTA (magnification x 2500)



In other experiments, the use of PUI/UAI has not shown better removal of the smear layer, even with the combined use of NaOCl and EDTA [21, 22].

There is no data on the removal of the smear layer by using PUI/UAI with distilled water (Fig. 7) [17, 23].

Fig. 7. Scanogram of dentin from the apical third of the root canal, irrigated with activated saline solution (magnification x 2500)



Lee et al. [24] and Sluis et al. [25] investigated the ability of ultrasonically activated irrigation to clean debris from artificially created hard-to-reach areas of the root canal. The authors developed *ex vivo* models with artificially created indentations in the root canals. Thus, the authors have found that the greater the enlargement and the taper of the root canal, the better the removal of debris by PUI/UAI. Rõdig et al. [26] have demonstrated that the size of the apical enlargement does not affect the cleaning ability of PUI/UAI. This result contradicts the claim that greater apical preparation improves the effectiveness of ultrasonically activated irrigation with NaOCl [27]. Cameron [18], Goodman et al. [15] and Jiang et al. [28] have claimed that the cleaning of debris from the depressions of the root canal is improved when the vibration of the file is directed to these areas. In order to achieve penetration of the solution into hard-to-reach areas, some authors have considered the possibility of PUI/UAI disperse the solution in the lateral canals. De Gregorio et al. [29] have found that the ultrasonically activated solution enters the lateral canals, in contrast to a solution applied by a syringe or negative pressure irrigation. Spoorthy et al. [30] have reported similar results.

The required amount of the irrigant, its methods of application and the required time for stay in the root canal have also been extensively studied. Intermittent irrigation is the more popular method compared to continuous irrigation and the use of PUI/UAI. Intermittent irrigation comprises syringe irrigation filling the entire root canal with the irrigant and the following activation of the solution with ultrasonic energy. The irrigations and activations are repeated. This method is more time-consuming due to the continuous interruptions of the technique. Activation with ultrasound requires constant renovation of the solution due to the saturation of the used solution with dentin debris, tissue, bacteria and biofilm. That increases the viscosity of the solution, which in turn reduces the possibility of propagation of ultrasonic energy in the used solution [11]. The results have shown that the continuous renovation of NaOCl increases the activity of the solution itself [31, 32] and improves the cleaning of the root canal. These studies confirm that the cleaning of the root canal wall in *ex vivo* models also increases with the extension of the PUI/UAI use time. Continuous (non-intermittent) irrigation requires a system that provides immediate evacuation of the contaminated/saturated irrigant in order to deliver a continuous fresh solution to the root canal. The GentleWave System (Sonendo, *USA*) is a modern device that generates sound and ultrasound waves of different frequencies when applying a slight apical negative pressure. The device combines the concept of minimally invasive endodontic treatment with the maximum degree of disinfection and removal of the smear layer and debris [33, 34].

Ideally, the irrigating solution should reach the apical one-third of the canal. Unfortunately, studies have confirmed that the most critical is the time and not the method of irrigation (either intermittent or continuous) [35]. Lev et al. [36] claim that 1 min of canal irrigation with PUI/UAI corresponds to 3 min of non-activated irrigation.

More effective cleaning has been observed in straight root canals. This is due to the fact that in them, the tip of the ultrasonic instrument is about 1 mm from the end of the apex, while in curved root canals, the tip of the instrument rests on the inner wall of the canal curve, which limits the activation of the solution in the apical area [32].

COMPLICATIONS:

Unfortunately, the extrusion of debris and the irrigant in the periapical space has been observed as a complication of the use of PUI/UAI. Malki et al. [37] have shown that the movement of the irrigant extends to a distance of about 3 mm beyond the tip of the ultrasonic instrument. Munoz et al. [38] argue that the use of PUI/UAI certainly transports the irrigant beyond the tooth apex. Malentacca et al. [39] have not observed irrigation extrusion when the tip of the ultrasonic instrument is placed 3 and 5 mm from the physiological narrowing. Extrusion has been observed when the tip of the instrument is 1 mm from the tooth apex.

CONCLUSION:

In conclusion, it can be said that the use of ultrasonic activation of the irrigating solution after root canal preparation significantly improves the removal of debris from hard-to-reach areas such as isthmuses, lateral canals and the apical delta [17, 29, 32, 37]. Empirically, this leads to better clinical outcomes of endodontic treatment.

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