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Effectiveness of Vapor Lock Effect Removal in Endo Training Blocks: Manual Dynamic Agitation versus Passive Ultrasonic Irrigation

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Abstract: Root canal cleaning plays an important role in endodontics. In most cases, root canal cleaning is performed using irrigants, such as sodium hypochlorite or EDTA (ethylenediaminetetraacetic acid). The efficacy of these irrigants may be compromised by different phenomena, such as vapor lock. Different methods can be used to overcome this problem; in this paper, we compare the efficacy of two such methods: manual dynamic agitation (MDA) and passive ultrasonic irrigation (PUI). We shaped 50 endo training blocks, which were divided into two groups of 25 samples each, into MDA or PUI groups. In both groups, the vapor lock was produced by delivering a watery solution using a disposable syringe with a tip-opened needle. Using the MDA technique, vapor lock was removed in 15/25 cases. The PUI technique produced the same results in 17/25 cases, where vapor lock was only reduced, not removed. The MDA method produced an average reduction in vapor lock of 80%, whereas the PUI method yielded a 55% reduction. The differences among groups were assessed through a Mann–Whitney U test, and the results had a p-value of 0.0013, which was considered to be statistically significant. The MDA method was able to effectively remove vapor lock. PUI, however, was only able to reduce but not remove vapor lock.

Keywords: manual dynamic agitation; passive ultrasonic irrigation; vapor lock; endodontics; endo training blocks; endodontic irrigation; ultrasonic activation; root canal irrigants

1. Introduction

Endodontic treatment involves a procedure composed of the following sequence of steps: tooth anesthesia, operative field isolation, opening of the pulp chamber, canal scouting, shaping and cleansing of the canals, and three-dimensional (3D) obturation [1]. These phases lead to root canal disinfection, shaping [2,3], and filling [4]. All the steps are important for achieving endodontic success, but cleansing has an essential role in reducing the bacterial load inside the root canal system [5]. Cleansing can be

mechanical and performed with endodontic instruments during the shaping phase [6], or it can be chemical and performed with irrigants [7].

Irrigants can be divided into (1) substances with strong antibacterial properties, such as 5% sodium hypochlorite, and (2) chelating substances, such as EDTA (ethylenediaminetetraacetic acid) [5]. However, the use of irrigants has some challenges, one of which is their inability to eliminate *Streptococcus faecalis* bacteria or withstand the action of 5% concentrated sodium hypochlorite [8]. Irrigants, if extruded beyond the apex, can damage the surrounding periodontal tissues [9]. Some physical phenomena are responsible for preventing their adequate action in the apical third or preventing their action within a reasonable time. Among these phenomena is the vapor lock effect [10].

1.1. Vapor Lock

The vapor lock phenomenon entails the formation of an air or gas bubble inside a close-ended system. The bubbles prevent the action of the irrigants and osmosis. The canal region located beyond the bubble then cannot be reached, usually at the apical third [11]. This bubble can form due to capillarity and superficial tension phenomena during the delivery of irrigants inside the root canal system and the activity of the irrigants that, reacting with root canal tissues, produce different gases, including oxygen [10]. The removal of these bubbles, especially if located deep inside the canal, can be extremely complicated due to the difficulty in reaching the apex with the needle of the syringe containing the irrigants [12,13]. Inserting the needle deep inside the canal leads to a higher risk of extrusion of the irrigants, especially if the needle tip is located in proximity to the apical foramen [7].

Experimental data in the literature on the formation of vapor lock in experimental conditions were provided by different studies. The data reported by Boutsioukis et al. indicated how the formation of vapor lock is influenced by the irrigation method. They showed how the use of a lateral opening needle favors the formation of vapor lock in more samples compared to using an apical opening needle through positive pressure irrigation (100/160 close-ended needle compared to 54/160 open-ended needles) [14]. The patency of the channels also seems to influence the formation of vapor lock according to Vera and colleagues [10,15], whose results were confirmed by Castelo-Baz et al. [16] and Sáinz-Pardo et al., who considered the penetration of the liquid irrigating the apical third to be disadvantaged due to the presence of a closed canal system [17].

The literature shows how the methods for improving the activity of sodium hypochlorite are also effective in removing vapor lock. The methods used for the activation of hypochlorite and the removal of the vapor lock effect include passive ultrasonic irrigation (PUI) [18], manual dynamic agitation (MDA) [19,20], a sonic endoactivator [21], continuous ultrasonic irrigation (CUI) [22], and photon-induced photoacoustic streaming (PIPS) [23].

1.2. Manual Dynamic Agitation (MDA) and Passive Ultrasonic Iirrigation (PUI)

Different techniques favor the elimination of vapor lock [8]: (1) MDA [19], which consists of activating a canal irrigant by shaking a small K-file or a gutta-percha cone inside the canal after shaping, using movement from the bottom to the top with a width of 23 mm [18,24], and (2) PUI, which is based on the transmission of acoustic energy from the file on an irrigant in the root canal. The energy is transmitted by means of ultrasonic waves and can induce acoustic streaming and irrigation of the irrigant. The ultrasonic tip, after the channel shaping phase, is introduced inside the channel filled with the irrigant, and the ultrasonic tip is free to move inside the canal without touching the walls [19]. The main phenomenon associated with PUI, which determines the removal of debris and activation of the irrigants, is acoustic microstreaming, which consists of the rapid circular movement of the fluid similar to that of a vortex around the activating tip.

In this study, we aimed to compare these two different methods to determine the efficacy of the action of irrigants in removing vapor lock.

2. Materials and Methods

The samples used include 50 S-shaped endo training blocks (Dentsply Maillefer, Ballaigues, Switzerland) made of resin, with a 0.15–0.30 mm ø and a 2% taper (Maillefer-Dentsply, Ballaigues, Switzerland) [25]. Each sample was shaped by a dentist, with at least three years of experience in the field of endodontics, using the following sequence of instruments to shape the root-canal system: a No. 10 K-file to establish the 16-mm working length (Maillefer-Dentsply, Ballaigues, Switzerland), pathfiles no. 1, 2, and 3 (Maillefer-Dentsply, Ballaigues, Switzerland) [26] to produce the glide path [26], and ProTaper Universal instruments S1-S2-F1-F2-F3 (Maillefer-Dentsply, Ballaigues, Switzerland) for the final phase of shaping [3]. The final shaped endo training blocks were divided into two groups, composed of 25 samples each, assigned to either MDA [27] or PUI [28].

In the evaluation of MDA efficacy [29] performed on the endo training block similar to the close-ended systems whose terminal portions were closed using orthodontic wax, a watery solution was delivered inside the endo training blocks using a disposable syringe, with a tip-opened 25 gauge diameter needle located 5 mm beyond the entrance of the resin block. This technique is commonly known as positive pressure irrigation (PPI) (Figure 1) [30]. In the cases where vapor lock presence was demonstrated, the MDA [20] method was performed with a dedicated F3 gutta-percha cone, using back and forth movements inside the canal for 10 s. In the evaluation of PUI efficacy performed on the endo training block similar to the close-ended systems whose terminal portion was closed using orthodontic wax, a watery solution was delivered inside the endo training blocks using a disposable syringe, with a tip-opened 25 G diameter needle, located 5 mm beyond the entrance of the resin block; this technique is commonly known as PPI [31]. In the cases where vapor lock presence was demonstrated, the PUI method was performed using a Woodpecker ultrasonic tip (28/32 kHz) (Guilin Woodpecker Medical Instrument, Guilin, Guangxi, China) [32], with a 0.8 mm ø mounted on a Satelec handle(Satelec, Bordeaux, France), acting inside the block for 10 s.

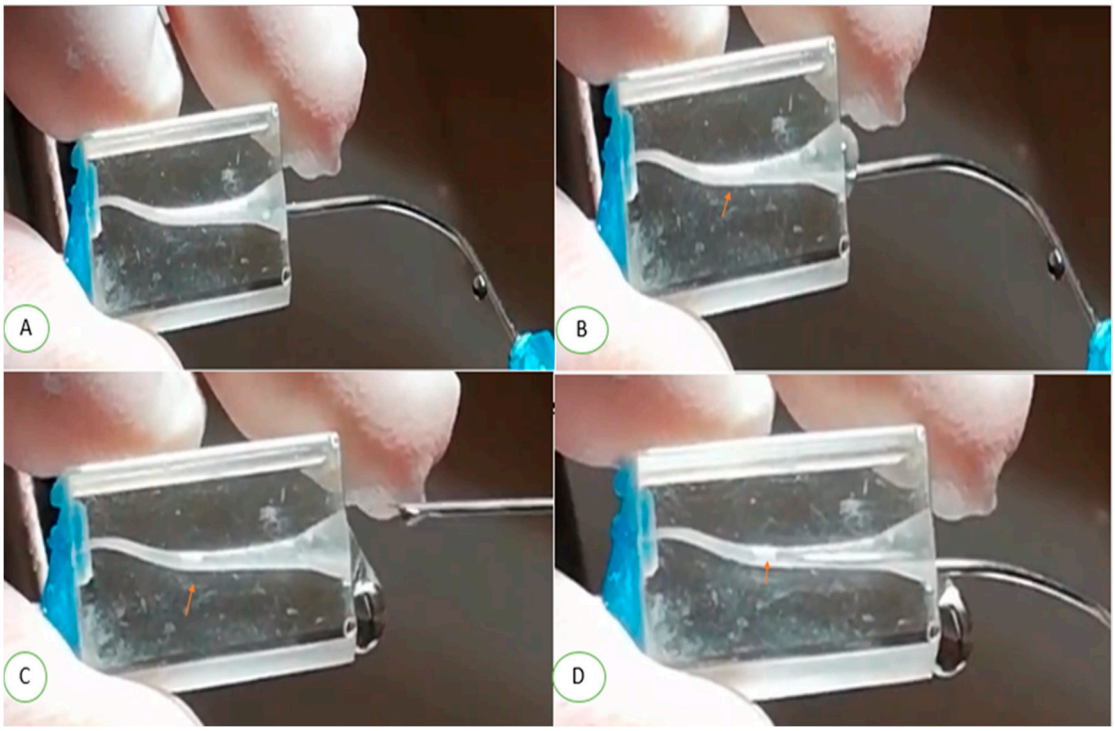

Figure 1. Sequence introduction of irrigants using positive pressure irrigation (PPI) with vapor lock formation in an endo training block with the apex closed by orthodontic wax: (**A**) liquid introduction, (**B**) initial formation of the vapor lock in the middle third, (**C**) vapor lock stabilization in the middle third, and (**D**) failed attempt to remove the vapor lock by re-treating the liquid using PPI.

The photos were recorded with a digital camera (Canon 1100D, Tokyo, Japan) at a fixed position and magnification using stable supports for the digital camera and specimens. Two photos were captured for each block both before and after the use of the irrigation activation method (Figure 2). Each photo was analyzed on Image J software [33] to calculate the vapor lock area projection. Data expressed as a percentage of vapor lock reduction are reported in Table 1.

Table 1. Results. Legend: ++ = removal (100%); – = not removed (0%); reduction expressed as a percentage.

Test Number	Manual Dynamic Agitation (MDA) Vapor Lock			Test Number	Passive Ultrasonic Agitation (PUI) Vapor Lock		
	Un Removed	Reduction (%)	Removal		Un Removed	Reduction (%)	Removal
1			++ [1]	26	– [2]		
2			++	27		41.253	
3			++	28	–		
4		22.23		29	–		
5		27.67		30		79.89	
6		88.23		31	–		
7			++	32	–		
8			++	33	–		
9			++	34	–		
10			++	35		75.994	
11		44.155		36		77.1564	
12		40.64		37		74.884	
13			++	38		80	
14			++	39		67.645	
15			++	40		78.165	
16	–			41		72.854	
17			++	42		72.65	
18			++	43		80.175	
19			++	44		69.536	
20		70.14		45		77.7	
21		66.783		46		77.854	
22		49.693		47		74.34	
23	–			48			++
24		92.073		49		70.92	
25			++	50		93.92	
Total	1	9	15		7	17	1

[1] ++ = removal (100%); [2] – = not removed (0%);

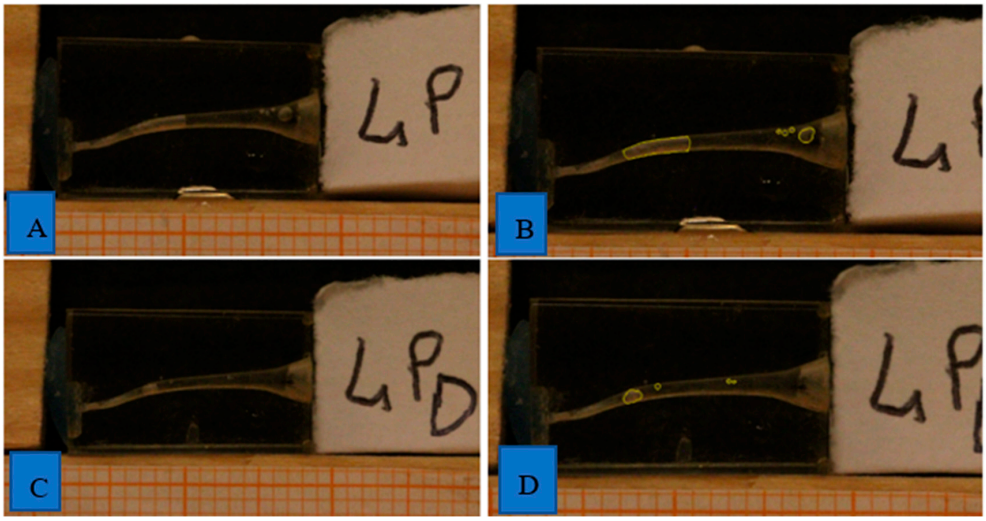

Figure 2. (**A**) After the formation of the vapor lock by PPI, the endo training blocks were numbered, positioned, and photographed on a support with a black background and a millimeter scale; (**C**) the block after activation by manual dynamic agitation (MDA) is repositioned on the support and photographed; (**B**,**D**) the photos were analyzed in Image J, and the contours of the bubbles were delimited.

Statistical Analysis

GraphPad Prism 8.0.2 (GraphPad Software Inc., San Diego, CA, USA) was used for the statistical analysis. In particular, the difference between the two groups was assessed through a Mann–Whitney U test (a non-parametric test for independent samples). A *p*-value lower than 0.05 was considered to be the threshold of statistical significance.

3. Results

Using the MDA technique, the vapor lock effect was completely removed in 15 of the 25 cases. Using the PUI technique, the vapor lock was removed in only one sample out of 25. Vapor lock was reduced using MDA in nine samples compared to the 17 samples with PUI. PUI was ineffective at either reducing or removing vapor lock in seven samples compared to the single sample in MDA. The MDA method produced an average percentage reduction in vapor lock of 80%, whereas the PUI method produced a 55% reduction. A detailed representation of the results of our tests is provided in Table 1 and Figure 3.

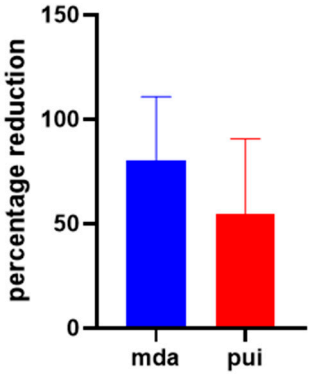

Figure 3. Outcomes of vapor lock removal with passive ultrasonic irrigation (PUI) or MDA. The average reduction in vapor lock was 80% with MDA and 54.6% with PUI; *p*-value = 0.0013, Mann–Whitney U test = 153.

The difference in the percentage of vapor lock removal assessed with the Mann–Whitney U test showed a significantly higher reduction (Figure 3) for MDA compared to PUI (p-value = 0.0013).

4. Discussion

In our experiment, transparent resin-made endo training blocks were chosen to visualize the vapor lock effect, which is not possible using diaphanized teeth. This visualization was performed during the shaping phase before using the ProTaper Universal F3 (Maillefer-Dentsply, Ballaigues, Switzerland) instrument to best approximate the natural model [17].

The two techniques outlined above provided differing results for the removal of the vapor block. PUI demonstrated ineffective removal of vapor lock (Figure 4), producing only a reduction due to the fragmentation of the bubbles obtained by acoustic streaming [34]. These bubbles, which indicate the formation of vapor, were mainly produced in the apical third.

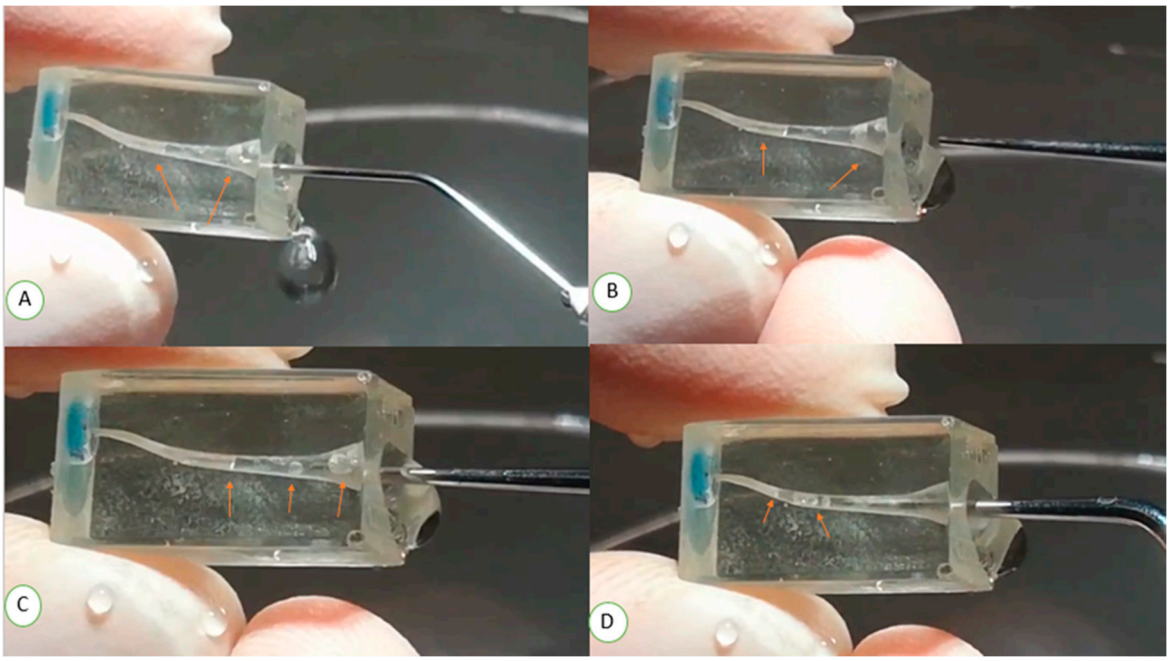

Figure 4. Vapor lock removal sequence using PUI in endo training blocks (s-shaped) whose apex was closed using orthodontic wax. (**A**) Introduction of PPI irrigants with vapor lock formation in the coronal third and apical third. (**B**) Once the vapor lock was formed, it was removed by means of an ultrasonic woodpecker tip with a diameter of 0.6, a PUI technique. (**C**) Initial fragmentation of the vapor lock in the apical third with formation of small bubbles. (**D**) Further removal of the vapor look in the apical third, showing how the liquid is pushed more apically.

In the literature, five studies described PUI as related to vapor block, whereas two studies were related to MDA (Table 2).

Table 2. Characteristics of the studies in the literature; this research was conducted on PubMed and EBSCO, with the following keywords: vapor, vapor lock, and vapour lock, producing 87 records. After removing overlaps and screening the articles, the listed articles were considered [35]. PIPS—photon- induced photoacoustic streaming; CUI—continuous ultrasonic irrigation.

Author, Data, Journal	Characteristics of the Samples	Investigation Method	Endodontic Instruments Used for Shaping	Irrigation Activation Method	Type of Data Recorded	Results
Agarwal et al. 2017, *Contemp Dent Pract* [36]	60 extracted teeth decoronated	CBCT (cone beam computed tomography)	Protaper universal f4 (Maillefer) of up to 40 size 0.06 taper in tips	PUI.20 Sonic Endoactivator, 20 MDA (k file) 0.20	Absence of vapor lock	PUI 18/20 Sonic 16/20 MDA 10/20
Su et al. 2017, Beijing Da Xue Xue Bao Yi Xue Ban [11]	40 canal simulations	CBCT	Wave one primary (Maillefer) of up to 25 size 0.07 taper in tips	PUI, 10 PIPS, 10 Sonic Endoactivator, 10 MDA (cone gutta-percha) 0.10	Volume reduction as a percentage of vapor lock)	PUI 70.37% PIPS. 100% Sonic 63.54% MDA 100%
Castelo-Baz et al. 2016 J Clin Exp Dent. [22]	60 diaphanized and decoronated teeth	Direct observation of the sample	GTX (Dentsply Tulsa Dental) 20, 0.04; 20, 0.06; 30, 0.06	PPI (needle) 20 PUI 20 CUI 20	Removal of the vapor lock	PPI 0/20 PUI. 8/20 CUI 18/20
Castelo-Baz et al. 2012 J Endod. [16]	30 open system, 30 closed system	Direct observation of the sample	Protaper universal f3 (Maillefer) of up to 30 size 0.09 taper in tips	PPI (needle) 20 PUI 20 CUI 20	Removal of the vapor lock	PPI 0/20 PUI 14/20 CUI 16/20
Sáinz-Pardo et al. 2014 Braz Dent J [17]	60 extracted teeth (30 closed system 30 open system)	RX (periapical radiography)	Profile rotary files (Maillefer) of up to 30 size 0.06 taper	PUI 20 PPI (needle) 20 Sonic 20	Removal of the vapor lock	PUI 7/10 (closed system) 10/10 (open system) PPI 3/10 (closed system) 10/10 (open system)
Vera et al. 2012 J Endod. [15]	In vivo 43 teeth 22 patency 21 no patency	RX periapical	K 3 System (Sybron Dental Specialties) 40/06	PPI (needle) 43	Absence of vapor lock	11/22 vapor lock absent group patency 18/21 vapor lock absent group no patency
Vera et al. 2012 J Endod. [10]	In vivo 71 teeth 36 patencyweiqi35 no patency	RX periapical	Protaper universal f3 (Maillefer) of up to 30 size 0.08 taper in tips	PPI 71	Absence of vapor lock	25/36 vapor lock absent group patency 21/35 vapor lock absent group no patency
Boutsioukis et al. 2014 Int Endod J [14]	20 canal simulations (×16 = 320 combinations)	Stereoscopic microscope	Race (FKG Dentaire, La Chaux-de-Fonds, Switzerland) to either size 35, 0.04 taper (group A) or size 50, 0.04 taper	PPI (needle) open ended and closed ended needle	Absence of vapor lock	160 needle close-ended open 60 absent vapor lock 160 needle open-ended 106 absent vapor lock

The most recent study investigating the removal of vapor lock was that by Agarwal et al. in 2017 [36], where three effective methods for the removal of vapor lock were highlighted: MDA, PUI, and endoactivator. In this study, an experiment was conducted on closed channel extracted teeth using irrigants and 3% sodium hypochlorite with a radiopaque solution of cesium chloride. The evaluation was performed using CBCT (cone beam computed tomography). The results of the study conducted by Agarwal et al. partially agree with ours; on 20 samples, the removal of vapor lock occurred in 90% of the cases (18 samples) using endoactivator butin, in 80% of the cases using sonic systems (16 samples), and in 50% of the cases (10 samples) using MDA. The study had a similar design to the present work. The decoronation of the dental elements appeared to occur at a distance of 17 mm compared to the 15 mm with the endo training block. In both cases, a closed channel system was reproduced, and the shaping method was the same. The differences in the results are due to evaluating the vapor lock through the use of CBCT and MDA using K-files, which produce a different result than when using gutta-percha cones. We think that, by using a gutta-percha cone with the same diameter and dimension as the shaped canal, it is possible to push the liquid beyond the bubble without producing a fragmentation, as demonstrated by Su et al. in 2017, who, through MDA, achieved a 100% volume reduction [11].

A systematic review performed by Dioguardi et al. in 2019 [37] also found, through meta-analysis, all studies on the formation of vapor lock following PPI and PUI on closed channel diaphanization teeth. Vapor lock was recreated using PPI and examined through the use of ink-impregnating liquids. The data in the literature on the removal of vapor lock by PUI or MDA agree with our data.

5. Conclusions

Based on the results, the vapor lock effect appears on close-ended root canal systems; however, in daily practice, it is less frequent because irrigation is performed inside open-ended root canal systems. The comparison between the data gathered from the international literature and our experiment on endo training blocks confirmed that the PUI method is not able to remove the vapor lock effect but can only reduce fragmenting bubbles, whereas MDA is an effective system. In our test, MDA produced an 80% reduction compared to the 55% by PUI.

PUI remains an excellent method to activate canal irrigants but produces only modest results for the removal of vapor lock compared with MDA.

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Conflicts of Interest: The authors declare no conflict of interest.

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