EGYPTIAN
DENTAL JOURNAL
www.eda-egypt.org

Vol. 68, 2995:3004, July, 2022

Print ISSN 0070-9484 • Online ISSN 2090-2360

Conservative Dentistry and Endodontics

Submit Date : 05-06-2022 • Accept Date : 26-06-2022 • Available online: 30-06-2022 • DOI : 10.21608/edj.2022.142620.2133

# EFFECT OF CONTINUOUS ULTRASONIC IRRIGATION AND DIODE LASER ACTIVATION ON APICAL EXTRUSION OF DEBRIS: IN VITRO STUDY

Ahmed A. Elmallawany [*], Yasser F Hussein [**], Magdy M. Ali [***], Yousra Aly [****] *and* Nehal F. Sharaf [****]

## *ABSTRACT*

**Aim:** To evaluate the effect of continuous ultrasonic and diode laser root canal irrigation activation techniques on apical extrusion of debris for extracted mesial mandibular molar roots.

**Materials and methods:** Forty extracted mandibular molars were used in this study. After teeth hemi-sectioning was done, forty mesio-buccal canals were mechanically prepared using Revo-S system files according to manufacturer instructions till size AS 35# and then, roots were randomly assigned to two equal groups according to the irrigation activation method: **Group (1)**: conventional syringe irrigation was used after mechanical preparation. This group was subdivided into 2 subgroups: **Subgroup (1A)**: conventional syringe irrigation with no laser and **subgroup (1B):** conventional syringe irrigation with diode laser. **Group (2):** Continuous Ultrasonic Irrigation (CUI) was used after mechanical preparation and further divided into two subgroups: **Subgroup (2A):** Continuous Ultrasonic Irrigation (CUI) with no laser and **subgroup (2B):** Continuous Ultrasonic Irrigation with diode laser. A modified version of Myers and Montgomery's experimental approach was employed to assess apically extruded debris. Debris were calculated by measuring difference of weight of Eppendorf tubes (before mechanical preparation W1 and after mechanical preparation and irrigation activation W2). All measurements were done using analytical balance.

**Results:** In all sub groups, no significant difference was shown, but the apical debris extruded was higher in **subgroup (2B)** (continuous ultrasonic irrigation with diode laser) then **subgroup (1B)** (conventional syringe irrigation with laser) followed by **subgroup (2A)** (continuous ultrasonic irrigation with no laser). The least amount of apical debris was in **subgroup (1A)** (conventional syringe irrigation with no laser).

**Conclusion:** Diode laser and continuous ultrasonic irrigation activation could be safely used for irrigation activation with minimal effect on apical extrusion of debris.

**Keywords:** Continuous ultrasonic irrigation, diode laser 810, apical extrusion of debris.

* Assistant Researcher at Restorative and Dental Materials Department, National Research Centre.
** Professor of Dental materials, Faculty of Dentistry, Minia University.
*** Professor of Endodontics, Faculty of Dentistry, Beni Suef University.
**** Associate Researcher Professor of Endodontics at Restorative and Dental Materials Department, National Research Centre.

## INTRODUCTION

The elimination of microorganisms from the root canals is the main factor for endodontic treatment success. During chemo-mechanical preparation, endodontic files and irrigating solutions eliminate the organic and inorganic tissues that enclose and harbor microorganisms and their byproducts.

Syringe irrigation (SI) has been described to be insufficiently capable to clean the apical third of root canal [1,2]. Irrigating solution and debris in root canals could be extruded beyond the apex reaching the periapical tissues during root canal preparation triggering severe pain [3,4,5,6].

Irrigating solutions are only capable of reaching dentin walls, not the intricate apical anatomy of root canals and lateral canals [7]. Numerous approaches have been researched, including ultrasonic, laser, and sonic activation to improve the efficiency of irrigating solutions [8,9,10]. Furthermore, techniques such as sonic and ultrasonic have been explored and developed to improve the dispersal and activation of the irrigant. Also, as an alternative to the traditional cleaning and disinfection methods, lasers have been offered [11].

Cavitation and pressure waves are caused by ultrasonic and pulsed middle infrared lasers within the root canal space. These two physical techniques are used for removing the smear layer [12]. In terms of clinical practice, the associated smear layer must be removed from canal because it may house packed microorganisms and contaminated material in the canal wall. [13,14].

The performance of lasers used in dentistry has been improved and many types of lasers have been considered in order to develop better treatment methods [15].

Bacteria, pulp tissue, dentin chips, and irritants are finally forced into the periapical tissues from the root canal, despite strict meticulous working length (WL) adjustment. The extrusion of these elements may result in unintended outcomes such as acute inflammatory response, post-instrumentation pain, and inter-appointment flare-up and prolonged periapical healing time [6,16]. As a result, avoiding debris extrusion during root canal treatment is considered a critical factor for root canal treatment success [17]. The aim of this study was to evaluate and compare the amount of apically extruded debris with continuous ultrasonic and diode laser irrigation activation.

## MATERIALS AND METHODS

### 1- Collection of teeth

Forty recently extracted human mandibular molars with completely formed roots were collected for this study. Roots with cracks, caries and resorptive defects were excluded. Teeth were carefully cleaned with curettes to remove the soft tissue remnants, then placed in 5.25 % sodium hypochlorite ($NaO^{cl}$) for one hour for surface disinfection.

Preoperative periapical radiographs of the extracted teeth were taken with parallel and mesial shift to check for number of canals, root caries, root canal calcification or pulp stones.

### 2-Teeth preparation

Hemi-sectioning of the teeth at the furcation level into mesial and distal roots were done using a low–speed diamond saw under water Isomet 1000. In this study, apically extruded debris were evaluated in mesio-buccal canals only. Access cavity preparation was made in each tooth and the mesio-buccal canals orifices were located. The patency of each canal was confirmed by inserting size 10 K file (Mani Inc, Japan) till the apical foramen to exclude teeth with root canal calcification or pulp stones. The working length (WL) was determined by passing file size10 K until seen coming out from the apex and then withdrawing it for 1 mm. Mesio-buccal canals were mechanically prepared using Revo-S[1] system files according to manufacturer instrructions at rpm 250 and torque 1.6 N\cm[2] starting by file SC1, SC2 and SU till size AS 35#.

### 3- Classification of the samples

From the 40 molars, the 40 mesial roots were randomly assigned to two equal groups according to irrigation activation method:

**Group (1)**: conventional syringe irrigation was used after mechanical preparation. This group was subdivided into 2 subgroups:

**Subgroup (1A)**: conventional syringe irrigation with no laser (irrigation was done using 30-gauge side vented needle[2] placed 2mm shorter of the working length).

**Subgroup (1B):** conventional syringe irrigation with diode laser. (Diode laser[3] was used for activation of 2.6 % NaOCl in the root canals. Device adjusted at power of 0.8 Watts, interval and duration of 20 seconds in a continuous mode using fiber core diameter 200 $\mu$m and length 20 mm without tip initiation).

**Group (2):** Continuous Ultrasonic Irrigation (CUI) was used after mechanical preparation and further divided into two subgroups:

**Subgroup (2A):** Continuous Ultrasonic Irrigation (CUI) with no laser (canals were cleaned, shaped and irrigated using the ProUltra PiezoFlow[4] that was used for activation of the irrigating solution according to manufacturer's recommendations). The stopper on the PiezoFlow needle was set 1 mm short of binding in the canals, but not more than 75% of the working length.

**Subgroup (2B):** Continuous Ultrasonic Irrigation with diode laser (the use of diode laser was performed as described before in subgroup 1B).

1 MICRO-MEGA®+, BESANCON cedex, France.
2 ENDO-TOP, PPH KERKAMED, Poland
3 PicassoLite, AMD, LASERS® LLC, USA
4 Dentsply Tulsa Dental Specialties, Tulsa, OK, USA.

### 4- Method of Evaluation

A modified version of the experimental model described by Myers and Montgomery (15) was used to evaluate the amount of apically extruded debris, empty Eppendorf tubes were numbered and weighed using an analytical balance three times and average weight was calculated (W1). Then, a hot instrument was used to create a hole in the stopper of the Eppendorf tubes. External root surface was covered with two layers of nail polish except for 1mm around the apical foramen. Mesial roots were inserted into these holes under pressure and a 27-gauge bent needle was inserted alongside the stopper to balance the air pressure. The whole apparatus was then assembled into a glass vial and the vial was covered with aluminum foil. Mesio-buccal canals were instrumented and irrigation activation was done for the root canals according to which subgroup they belong. After instrumentation and irrigation, the separated stoppers with the mesial roots were removed from the pre-weighed Eppendorf tubes.

The external root surface was flushed with 1ml distilled water into the tube to collect debris adhering to external root surface. Before weighing the dried debris, Eppendorf tubes were maintained in an incubator at 37°C for 15 days to evaporate the moisture. Eppendorf tubes were weighed again (W2) and weighing procedure was carried out again using the same balance and three consecutive weights were obtained for each tube, followed by calculating the mean. The amount of apically extruded debris was determined by subtracting the average weight of the pre-weighed Eppendorf tubes from the average weight of Eppendorf tubes containing the dried debris obtained from the three consecutive measurements (W2 –W1). All measurements were done using analytical balance.

### Statistical Analysis

The mean and standard deviation values were calculated for each group. Data were explored for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests. Data showed parametric (normal) distribution.

Independent sample t-test was used to compare between two groups in non-related samples. Two-way ANOVA test were used to test the interactions between different variables.

The significance level was set at P ≤ 0.05. Statistical analysis was performed with IBM® SPSS® Statistics Version 20 for Windows.

## RESULTS

### *Effect of laser activation on amount of apically extruded debris:*

**For both conventional syringe irrigation subgroups and Ultrasonic subgroups,** there was no statistically significant difference between subgroups 1A and 2A (No-laser subgroups) and between subgroups 1B and 2B (Laser subgroups) where ($p$=0.152) and ($p$=0.052) respectively.

The highest mean value was found in groups activated with laser (1B and 2B), while the least mean value was found in No-laser groups (1A and 2A). Table (1), Fig. (1).

### *Effect of irrigation method on amount of apically extruded debris:*

**For both No-laser groups and Laser groups,** there was no statistically significant difference between conventional subgroups (1A and 1B) and Ultrasonic subgroups (2A and 2B) where ($p$=0.820) and ($p$=0.348) respectively.

The highest mean value was found in ultrasonic subgroups (2A and 2B) groups, while the least mean value was found in conventional subgroups (1A and 1B). Table (1), Fig. (1).

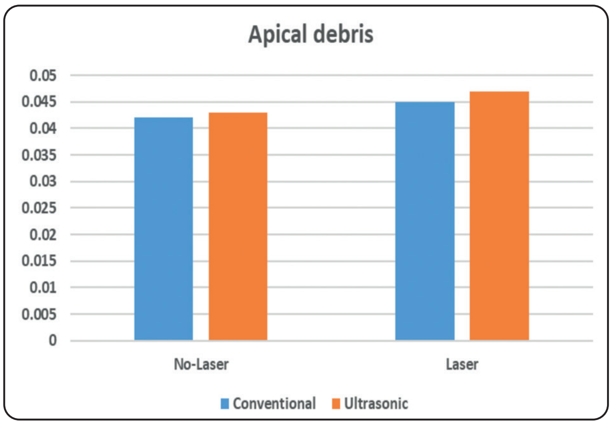


Fig. (1): Bar chart representing the mean values of apically extruded debris of different irrigant activation groups.

### Two-way ANOVA

Data in table (1) shows the results of Two-way ANOVA analysis for the interaction of different variables. The results showed that there was non-significant difference between conventional syringe irrigation group and continuous ultrasonic irrigation group. Also, laser had no statistically significant effect on amount of apically extruded debris.

TABLE (1): The mean, standard deviation (SD) values of apically extruded debris of different groups.

| Variables | Apical debris | | | | |
|---|---|---|---|---|---|
| | No-Laser | | Laser | | p-value |
| | Mean | SD | Mean | SD | |
| **Conventional syringe irrigation** | 0.042 | 0.006 | 0.045 | 0.003 | 0.152ns |
| **Continuous Ultrasonic Irrigation** | 0.043 | 0.004 | 0.047 | 0.003 | 0.052ns |
| ***p-value*** | **0.820ns** | | **0.348ns** | | |

*ns; non-significant (p>0.05)*

The interaction between the two variables had no statistically significant effect.

## DISCUSSION

For successful root canal treatment, it is mandatory to irrigate the entire root canal system. It is difficult to achieve a proper irrigation of the most apical part of the canal while avoiding extrusion of debris and irrigant beyond the apex [2,19,20]. Apical extrusion of debris beyond the apex results in postoperative discomfort and delayed periapical healing. The occurrence rate and frequency of extrusion has been observed to range between 1.4 to 16 % [21].

Many factors have been discovered to influence apical extrusion of debris and irrigant, including root canal anatomy, instrument size, type, canal preparation technique, apical enlargement, apical stop, irrigation solutions, techniques, and devices, as well as canal curvature and the presence of more than one canal [22,23,24,25,26,27]. As a result, irrigant extrusion leads to debris extrusion as mentioned by Yılmaz and Küçükay who stated that extruded debris and irrigants had a positive correlation with each other [28].

Moreover, according to Mitchell et al [29], increasing the apical diameter of the canal increased the risk of irrigants being extruded beyond root apex. That's why in our study, the apical canal preparation was standardized to (size35).

Single and straight roots were used in the majority of in vitro apical debris extrusion investigations [30,31,32]. In an in vivo clinical investigation, Arias et colleagues [33] discovered that the incidence of pain after endodontic treatment was much higher in teeth with curved root canals than in single and straight roots.

Similarly, Karataslioglu et al. [34] reported that the amount of apically extruded debris increased as the degree of canal curvature in teeth increased. Moreover, the mandibular molars were chosen because they have the uppermost reported incidence of postoperative pain [33]. Based on the literature, lower mandibular molar teeth with mesio-buccal canals were used in this investigation to model the most common clinical scenario and assess the quantity of apical debris extrusion with different irrigation activation techniques.

Thus, in the current investigation, Myers and Montgomery's well-known debris collection design was used [18], which was recommended by Tanalp and Güngör [6] to ensure standardization of all groups.

In the current study, although no significant difference was found between all sub groups but the highest amount of debris extrusion was seen in laser subgroups.

In the current study, laser irrigation activation extruded more debris (subgroups 2B and 1B). These results come in accordance with Kuşxtarcı and Er [35] who found that amount of apically extruded debris was greater in laser groups than conventional groups, while these results run against Yusufoglu et al [36] who stated that laser extrude less debris than manual irrigation. Cavitation is defined as the formation of vapor or a cavity containing bubbles within a fluid. The cavitation and pressure waves caused by laser activation of the irrigant in the canal could explain the more quantity of debris in laser subgroups [37]. Mechanism could be explained as in wet canals, sub-ablative setting of laser activation may cause large elliptical vapor bubbles formation, which expand, swell, and implode causing the irrigant to expand up to 1600 times its original volume [38]. After 100–200 $\mu$s, the bubble implodes, under pressure develops, and fluid is sucked back into the canal, causing secondary cavitation effects [39]. This expansion generates high pressure, allowing irrigation solutions to travel in three dimensions (3D) and improving root canal cleaning [40]. Furthermore, the laser-generated pressure waves promoted rapid fluid flow and appears to improve the efficacy of endodontic irrigant in eliminating the smear layer [41]. But unfortunately, this increased pressure could result in more vigorous irrigation, which could explain the increased amount of debris extruded apically. Because pressure waves produce transverse fluid movement, the chance of irrigant and debris extrusion beyond the apical constriction is higher with laser than ultrasonic activation and therefore this explains the more extrusion of debris in subgroup (1B) than subgroup (2A).

During laser activation in the root canal, apical fluid pressure may be affected by the distance between the fiber tip and the apex. [42]. To prevent some of the adverse consequences of typical laser applications, the fiber tip was generally used in the coronal region of the root canals in the current investigation, as in some earlier studies [43,44,45].

Previous research found that ultrasonic irrigant activation was more successful in eliminating artificially manufactured dentine debris in simulated canal expansions with broader tapers [46], As a result, the vibrating file of the ultrasonic devices only oscillates transversely rather than longitudinally towards the root axis. As a result, the solution's apical migration can be linked to the generation of ultrasonically produced waves at the solutionair interface, which causes trapped air in the root canal to be evacuated, allowing the solution to flow apically in the opposite direction [47]. This might explain larger amount of debris extrusion with ultrasonic activation than conventional subgroup. Also, ultrasonic energy might have led to apical precipitation of the debris.

Furthermore, with low irrigant extrusion, continuous ultrasonic irrigation was likely to reach the most apical area, which is consistent with various previous investigations on irrigant delivery [2,48,49,50,51]. Results of the current study showed non-significant difference between continuous ultrasonic and laser activated subgroups and conventional syringe subgroups, these results are in accordance with peeters et al [52] and sharma et al [53], who evaluated laser activated and ultrasonic irrigation procedures, and proved the safety of both activation techniques regarding their effect on apical extrusion of debris.

While the continuous ultrasonic needle was limited to 75 % of the working length; with an average WL of 19–20 mm in the mandibular molar, the needle tip should be inserted 4–5 mm distant from the canal terminus. It's probable that continuous ultrasonic needle's position was distant from the canal termination resulted in less irrigant extrusion into the periapical region which subsequently resulted in minimal extrusion of debris [54].

The results of ultrasonic activation also come with Karatas et al. [26] who stated that ultrasonic extruded more debris than the needle technique, with no significant difference.

In the existing investigation, the conventional syringe subgroup (1A) needle tip was 2 mm short of WL. The depth of the needle tip affects irrigant extrusion as more coronally the needle is situated, the created apical pressure will be diminished, but the irrigant exchange process will be less efficient [55]. Extrusion occurred even though the suggested side-vented needle was set away from the apex. The needle was put shorter of the WL by 2 mm or before binding for standardization purpose, and needle binding into the root canal walls was forbidden to avoid forcing irrigant and debris into the periapical area. To avoid periapical extrusion of irrigants, conventional syringe irrigation was done with gentle pressure [56].

The probability of irrigants extrusion from the apex was raised when the needle was inserted 2mm distant from the apex [57]. The side-vented is closed apically, generating more pressure on the root canal walls and improving the hydrodynamic activation of an irrigant, as well as minimizing the chances of apical extrusion, which enables the irrigant to reflux and causes added debris to be moved coronally, decreasing the unintended entrance of debris into the periapical tissues(58).

In the current investigation, regardless of the rotary system used for mechanical preparation of the canals, all instrumentation and irrigation approaches resulted in debris ejection. This comes in accordance with previous studies that showed that all instrumentation approaches cause debris extrusion through the periapical area [59,60,61,62].

Periapical tissues may act as a physical barrier, preventing debris from being extruded. Salzgeber and Brilliant (63) revealed that vital tissues aid in the control of irrigating solution apical and lateral penetration. There was no periapical tissue in our investigation that might operate as a barrier against apical debris ejection. This aspect bounds the generalization of our findings to the clinical setting, which is regarded as a restriction in most of the investigations (64,65,66,67).

## CONCLUSION

Diode laser and continuous ultrasonic irrigation activation could be safely used for irrigation activation with minimal effect on apical extrusion of debris. But great care should be considered for tip position of diode laser inside root canals and laser parameters adjustment.

### Recommendations

We recommend using either laser or continuous ultrasonic irrigation activation techniques for canal debridement. We recommend to explore the ideal laser activation time and other parameters to guarantee that cavitation and pressure will generate minimal extrusion of debris and irrigant during root canal therapy.

**Interest Conflict:** none declared to the current research.

**Funding:** Self-funded.

## REFERENCES

1. Alkahtani A, Al Khudhairi T, Anil S. A comparative study of the debridement efficacy and apical extrusion of dynamic and passive root canal irrigation systems. BMC Oral Health 2014; 14: 12.
2. Jamleh A, Fukumoto Y, Takatomo Y, Kobayashi C, Suda H, Adorno CG. A comparison between two negative pressure irrigation techniques in simulated immature tooth: an ex vivo study. Clin Oral Investig 2016; 20: 125-131.
3. Fukumoto Y, Kikuchi I, Yoshioka T, Kobayashi C, Suda H. An ex vivo evaluation of a new root canal irrigation technique with intracanal aspiration. Int Endod J 2006; 39: 93-99.
4. Desai P, Himel V. Comparative safety of various intracanal irrigation systems. J Endod 2009; 35: 545–9.
5. Elmsallati EA, Wadachi R, Suda H. Extrusion of debris after use of rotary nickel-titanium files with different pitch: a pilot study. Aust Endod J 2009; 35: 65–9.
6. Tanalp J, Güngör T. Apical extrusion of debris: a literature review of an inherent occurrence during root canal treatment. Int Endod J 2014; 47: 211–21.
7. Zehnder M. Root canal irrigants. J Endod 2006; 32: 389–98.
8. De Moor RJ, Blanken J, Meire M, Verdaasdonk R. Laser induced explosive vapor and cavitation resulting in effective irrigation of the root canal. Part 2: evaluation of the efficacy. Lasers in Surg and Med 2009; 41: 520–3.
9. DiVito E, Lloyd A. ER:YAG laser for 3-dimensional debridement of canal systems: use of photon-induced photoacoustic streaming. Dent Today 2012; 31: 124–7.
10. Pedulla E, Genovese C, Campagna E, Tempera G, Rapisarda E. Decontamination efficacy of photon-initiated photoacoustic streaming (PIPS) of irrigants using low-energy laser settings: an ex vivo study. Int Endod J 2012; 45: 865–70.
11. Blanken J, Moor RJGD, Meire M, Verdaasdonk R. Laser induced explosive vapor and cavitation resulting in effective irrigation of the root canal. Part 1: A visualization study. Lasers Surg Med. 2009;41(7):514-9.
12. George R, Rutley EB, Walsh LJ. Evaluation of Smear Layer: A Comparison of Automated Image Analysis versus Expert Observers. J Endod. 2008;34(8):999-1002.
13. Yamada R, Armas A, Goldman M, Lin P. A scanning elec-

tron microscopic comparison of a high volume final flush with several irrigating solutions: part 3. J Endod 1983; 9: 137- 142.

14. Baumgartner J, Mader C. A scanning electron microscopic evaluation of four root canal irrigation regimens. J Endod 1987; 13: 147-157.

15. Yamazaki R, Goya C, Yu D-G, Kimura Y, Matsumoto K. Effects of Erbium, Chromium:YSGG Laser Irradiation on Root Canal Walls: A Scanning Electron Microscopic and Thermographic Study. J Endod. 2001;27(1):9-12.

16. Hülsmann M, Rödig T, Nordmeyer S. Complications during root canal irrigation. Endod Top. 2009; 16:27-63. https://doi. org/10.1111/j.1601-1546.2009.00237.x

17. El-Din SN, Ali MM, Hassan R. Comparison of Apically Extruded Debris Associated with Different Irrigation Techniques after Removal of Intracanal Medicaments. Open Access Maced J Med Sci. 2021 Aug 20; 9(D):120-125.

18. Myers G and Montgomery S: A comparison of weights of debris extruded apically by conventional filing and canal master techniques. J Endod 1991; 17: 275-9.

19. Miller T, Baumgartner J. Comparison of the antimicrobial efficacy of irrigation using the EndoVac to endodontic needle delivery. J Endod 2010; 36: 509-511.

20. Haapasalo M, Shen Y, Qian W, Gao Y. Irrigation in endodontics. Dent Clin North Am 2010; 54: 291-312.

21. Siqueira JF, Rocas IN, Favieri A, Machado AG, Gahyva SM, Oliveira JC, et al. Incidence of postoperative pain after intraca-nal procedures based on an antimicrobial strategy. J Endod. 2002;28(6):457-60. https://doi. org/10.1097/00004770-200206000-00010 PMid:12067129

22. Caviedes-Bucheli J, Castellanos F, Vasquez N, Ulate E, Munoz HR. The influence of two reciprocating single-file and two rotary-file systems on the apical extrusion of debris and its biological relationship with symptomatic apical periodontitis. A systematic review and meta-analysis. Int Endod J. 2016; 49(3):255-70. https://doi.org/10.1111/iej.12452.PMid:25816688.

23. Gummadi A, Panchajanya S, Ashwathnarayana S, Santhosh L, Jaykumar T, Shetty A. Apical extrusion of debris following the use of single-file rotary/reciprocating systems, combined with syringe or ultrasonically-facilitated canal irrigation. J Conserv Dent. 2019; 22(4):351-5. https://doi.org/10.4103/jcd.jcd_14_19 PMid:31802818

24. Elmsallati EA, Wadachi R, Suda H. Extrusion of debris after use of rotary nickel-titanium files with different pitch: A pilot study. Aust Endod J. 2009;35(2):65-9. https://doi. org/10.1111/j.1747-4477.2008.00128x. PMid:19703077.

25. Gupta J, Nikhil V, Jha P. Corelation between machines assisted endodontic irrigant agitation and apical extrusion of debris and irrigant: a laboratory study. ScientificWorldJournal 2014; 2014: 346184. [CrossRef]

26. Karatas E, Ozsu D, Arslan H, Erdogan AS. Comparison of the effect of nonactivated self-adjusting file system, Vibringe, EndoVac, ultrasonic and needle irrigation on apical extrusion of debris. Int Endod J 2015; 48: 317–22.

27. Yeter KY, Evcil MS, Ayranci LB, Ersoy I. Weight of apically extruded debris following use of two canal instrumentation techniques and two designs of irrigation needles. Int Endod J 2013; 46: 795–9. [CrossRef ]

28. Yılmaz B, Küçükay ES. Evaluating the apically extruded debris and irrigants in different nickel–titanium instrumentation and irrigation techniques. Turk Endod J 2021;6:80-86.

29. Trevino E, Patwardhan A, Henry M, Perry G, Dybdal- Hargreaves N, Hargreaves K, Diogenes A. Effect of irrigants on the survival of human stem cells of the apical papilla in a platelet-rich plasma scaffold in human root tips. J Endod 2011; 37: 1109-1115.

30. Tambe VH, Nagmode PS, Vishwas JR et al. Evaluation of the amount of debris extruded apically by using conventional syringe, endovac and ultrasonic irrigation technique: An in vitro study. J Int Oral Health 2013; 5: 63–6.

31. Arslan H, Akc_ay M, Ertas H, C_apar ID, Saygılı G, Mes_e M. Effect of PIPS technique at different power settings on irrigating solution extrusion. Laser Med Sci 2015; 30: 1641– 5.

32. Uslu G, Özyürek T, Yılmaz K, Gündoğar M, Plotino G.. Apically extruded debris during root canal instrumentation with resiproc blue, hyflex edm and xp-endo shaper nickel titanium files. J Endod 2018; 44: 856–9.

33. Arias A, de la Macorra JC, Hidalgo JJ, Azabal M. Predictive models of pain following root canal treatment: a prospective clinical study. Int Endod J 2013; 46: 784–93.

34. Karataslıoglu E, Arslan H, Er G, Avcı E. Influence of canal curvature on the amount of apically extruded debris determined by using three-dimensional determination method. Aust Endod J 2019; 45: 216–24.

35. Kuşxtarcı A and Er K. Efficacy of Laser Activated Irrigation on Apically Extruded Debris with Different Preparation Systems. Photomedicine and Laser Surgery 2015; (33) 7: 384–389.

36. Yusufoglu S, Keskin N , Saricam E, Bozkurt D. Comparison of apical debris extrusion Using EDDY, passive ultrasonic activation and photon-initiated photoacoustic streaming irrigation activation devices. Aust Endod J 2020. doi: 10.1111/aej.12429 (cross ref)

37. Hmud R, Kahler WA, George R, Walsh LJ. Cavitational effects in aqueous endodontic irrigants generated by nearinfrared lasers. J Endod 2010;36:275–278.

38. Mir M, Gutknecht N, Poprawe R, Vanweersch L, Lampert F. Visualising the procedures in the influence of water on the ablation of dental hard tissue with erbium:yttrium-aluminium-garnet and erbium, chromium:yttrium-scandium-galliumgarnet laser pulses. Lasers Med Sci 2009;24:365–374.

39. De Moor RJ, Meire M, Goharkhay K, Moritz A, Vanobbergen J. Efficacy of ultrasonic versus laser-activated irrigation to remove artificially placed dentin debris plugs. J Endod 2010; 36:1580–1583.

40. Peeters HH, Suardita K. Efficacy of smear layer removal at the root tip by using ethylenediaminetetraacetic acid and erbium, chromium: yttrium, scandium, gallium garnet laser. J Endod 2011;37:1585–1589.

41. George R, Meyers IA, Walsh LJ. Laser Activation of Endodontic Irrigants with Improved Conical Laser Fiber Tips for Removing Smear Layer in the Apical Third of the Root Canal. J Endod. 2008;34(12):1524-7.

42. Peeters HH, De Moor RJ. Measurement of pressure changes during laser-activated irrigant by an erbium, chromium: yttrium, scandium, gallium, garnet laser. Lasers Med Sci 2014 [Epub ahead of print].

43. DiVito E, Olivi G. Review: Photoacoustic endodontics using PIPSTM: experimental background and clinical protocol. J LA&HA 2012;1:22–25.

44. Arslan H, Capar ID, Saygili G, Gok T, Akcay M. Effect of photon-initiated photoacoustic streaming on removal of apically placed dentinal debris. Int Endod J 2014;47:1072–1077.

45. Peeters HH, Mooduto L. Radiographic examination of apical extrusion of root canal irrigants during cavitation induced by Er, Cr:YSGG laser irradiation: an in vivo study. Clin Oral Investig 2013;17:2105–2112.

46. Van der Sluis LWM, Wu M-K, Wesselink PR. The efficacy of ultrasonic irrigation to remove artificially placed dentine debris from human root canals prepared using instruments of varying taper. Int Endod J 2005;38:764–768.

47. Peeters HH, Iskandar B, Suardita K, Suharto D. Visualization of Removal of Trapped Air from the Apical Region of the Straight Root Canal Models Generating 2-phase Intermittent Counter Flow during Ultrasonically Activated Irrigation. J Endod. 2014;40(6):857-61.

48. Tasdemir T, Er K, Celik D, Yildirim T. Effect of passive ultrasonic irrigation on apical extrusion of irrigating solution. Eur J Dent 2008; 2: 198-203.

49. Mitchell RP, Yang SE, Baumgartner JC. Comparison of apical extrusion of NaOCl using the EndoVac or needle irrigation of root canals. J Endod 2010; 36: 338-341.

50. Brown DC, Moore BK, Brown CE Jr, Newton CW. An in vitro study of apical extrusion of sodium hypochlorite during endodontic canal preparation. J Endod 1995; 21: 587-591.

51. Salzgeber R, Brilliant J. An in vivo evaluation of the penetration of an irrigating solution in root canals. J Endod 1977; 3: 394-398.

52. Huiz Peeters H, Suardita K, Mooduto L, Gutknecht N. Extrusion of irrigant in open apex teeth with periapical lesions following laser-activated irrigation and passive ultrasonic irrigation. Iran Endod J 2018; 13: 169–75.

53. Sharma R, Kumar V, Logani A, Chawla A, Sharma S, Koli B. Effect of gravity on periapical extrusion of irrigating solution with different irrigation protocols in immature anterior teeth. Eur Endod J 2020; 5: 150–4. [CrossRef ]

54. Middha M., et al. "Effect of continuous ultrasonic irrigation on postoperative pain in mandibular molars with nonvital pulps: a randomized clinical trial". International Endodontic Journal 50 (2017): 522-530.

55. Boutsioukis C, Lambrianidis T, Verhaagen B, Versluis M, Kastrinakis E, Wesselink PR, et al. The effect of needle-insertion depth on the irrigant flow in the root canal: evaluation using an unsteady computational fluid dynamics model. J Endod. 2010; 36(10):1664-8. https://doi.org/10.1016/j.joen.2010.06.023 PMid:20850673

56. Psimma, Z., et al., Effect of needle insertion depth and root canal curvature on irrigant extrusion ex vivo. Journal of endodontics, 39(4): p. 521-524 (2013).

57. Khademi, A., M. Yazdizadeh, and M. Feizianfard, Determination of the minimum instrumentation size for penetration of irrigants to the apical third of root canal systems. journal of endodontics, 32(5): p. 417-420 (2006).

58. Shalan L, Al-huwaizi H, fatalla A. Apical Extrusion of Debris and Irrigants after using Different Irrigation Needles and Systems with Different Depth of Penetration: (A Comparative Study). Biomed. & Pharmacol. J. (2018); 11 :( 1) 519-523.

59. Tinaz AC, Alacam T, Uzun O, Maden M, Kayaoglu G. The Effect of Disruption of Apical Constriction on Periapical Extrusion. J Endod. 2005;31(7):533-5.

60. Kocak S, Kocak MM, Sağlam BC, Turker SA, Sağsen B, Er O. Apical Extrusion of Debris Using Self-Adjusting File, Reciprocating Singlefile, and 2 Rotary Instrumentation Systems. J Endod. 2013;39(10):1278-80.37.

61. Ferraz CCR, Gomes NV, Gomes BPFA, Zaia AA, Teixeira FB, Souza- Filho FJ. Apical extrusion of debris and irrigants using two hand and three engine-driven instrumentation techniques. Int Endod J. 2001;34(5):354-8.

62. Kuştarcı A, Akpınar KE, Sumer Z, Er K, Bek B. Apical extrusion of intracanal bacteria following use of various instrumentation techniques. Int Endod J. 2008;41(12):1066-71

63. Salzgeber RM, Brilliant JD. An in vivo evaluation of the penetration of an irrigating solution in root canals. J Endod 1977;3:394–398.

64. Kustarci A, Akpınar KE, Er K. Apical extrusion of intracanal debris and irrigant following use of various instrumentation techniques. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;105:257–262.

65. Kustarci A, Altunbas D, Akpınar KE. Comparative study of apically extruded debris using one manual and two rotary instrumentation techniques for endodontic retreatment. J Dent Sci 2012;7:1–6.

66. Bu¨rklein S, Hinschitza K, Dammaschke T, Scha¨fer E. Shaping ability and cleaning effectiveness of two single-file systems in severely curved root canals of extracted teeth: Reciproc and WaveOne versus Mtwo and ProTaper. Int Endod J 2012;45:449–461.

67. Kirchhoff AL, Fariniuk LF, Mello I. Apical extrusion of debris in flat-oval root canals after using different instrumentation systems. J Endod 2014;41:237–241.