ACTA ODONTOLOGICA SCANDINAVICA
2022, VOL. 80, NO. 8, 588–595
https://doi.org/10.1080/00016357.2022.2061591

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REVIEW ARTICLE

Efficacy of sonic and ultrasonic activation during endodontic treatment: a Meta-analysis of *in vitro* studies

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ABSTRACT

Objective: To ensure a successful endodontic treatment, it is important to have a proper disinfection of the root canal. The current study compares the root canal cleanliness and smear layer score between sonic and ultrasonic activation.
Method: Systematic literature review was implemented, using 12 databases. All *in vitro* studies comparing the efficacy of sonic and ultrasonic activation and reporting at least one outcome of interest were included.
Results: At the apical level, pooling the data in the random-effects model (I^2=64%, $p = .1$) revealed a statistically significant lower smear layer score within the sonic activation group (MD-0.48; 95% CI-0.92, −0.04; $p = .03$). Furthermore, there was a statistically significant lower push-out bond strength value among the sonic group, in contrast to the ultrasonic group at the middle (MD-0.69; 95% CI-1.13, −0.25; $p = .002$) and at the apical levels (MD-0.78; 95% CI-1.09, −0.46; $p < .0001$) of the root canal.
Conclusions: Sonic activation accomplished advancement relative to ultrasonic agitation in removing the smear layer, while ultrasonic activation resulted in significant cohesion between the sealers and the dentine tubules, decreasing the vulnerability of apical leakage and tooth fracture.

ARTICLE HISTORY
Received 23 August 2021
Revised 27 March 2022
Accepted 29 March 2022

KEYWORDS
Disinfection; endodontics; root canal irrigants; sodium hypochlorite; ultrasonics

Introduction

Endodontic treatment aims to thoroughly disinfect the root canal and to reduce the bacteriologic status. The accomplishment of such purposes entail an efficient chemo-mechanical preparation, as well as proper obturation of the root canal system [1]. Canal's complex anatomy, mainly accessory and irregular canals, makes it extremely difficult to completely clean and seal all the ramifications of the canal system through chemo-mechanical preparation [2]. Canal cleanliness consists in the complete cleaning of the complex anatomy of the root canal system (lateral canals, isthmuses, fins and accessory canals). This is influenced by proper removal of debris and smear layer [3,4]. After preparation, a smear layer consists of organic and inorganic components, like dentine debris, microorganisms and necrotic tissue. This layer reduces the ability of root canal irrigants, and intracanal drugs to penetrate into the dentinal tubules adequately [5,6]. Smear layer scores are used to measure the percentage of smear layer covering the dentinal tubules and measure if dentinal tubules are visible and open [3]. Also, there are debris scores, to evaluate the percentage of the canal wall covered by dentine chips, pulp remnants and particles loosely attached to the canal wall [3]. Furthermore, close to 60% of the root canal surface might remain untouched by endodontic instruments using rotary files, which lead to inconvenient debridement and disinfection of the entire canal system [7]. Employment of irrigant solutions alone is found to be inappropriate to accomplish the complete elimination of debris and to kill the microorganisms, remove the smear layer, and eliminate the pulp residues within the canal system [8]. To enhance the distribution and flow of the agitated solutions during endodontic treatment, several strategies have been advocated.

To date, various mechanical, chemical, and thermal techniques have been proposed to achieve the desired cleaning [9]. On the contrary, none of these approaches alone or in combination succeeded in perfectly cleaning the root canal system. Additionally, such methods might be associated with adverse events such as peri-apical inflammation and irritation, along with post-operative flare-up. Accordingly, adjunct methods such as ultrasonic and sonic devices have been reported to alleviate/improve the cleaning efficacy and disinfection ability of the different irrigants [10,11].

Ultrasonic irrigant activation (UIA) is an irrigation protocol that uses files or smooth wires oscillating freely in the root canal producing powerful acoustic microstreaming. It enhances noticeably the efficacy of irrigants in eliminating inorganic and organic debris from the root canal, and promotes cavitation and acoustic transmission through operating at high frequency (25 to 30 kHz) [12]. However, such high-

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/00016357.2022.2061591

frequency leads to the disruption of the oscillating tip of the ultrasonic devices compromising the treatment, in the event that it provokes a blockage in the canal, compromising the outcome of the treatment. This factor may also explain the occasional inefficiency of ultrasonic activation, particularly in the apical part of the curved root canals. Moreover, UIA might be associated with apical zipping, canal deviation, and the root canal's perforation, particularly within a curved root canal. Sonic activation operates through low-frequency vibration (1–6 kHz) using flexible tips linked to an air sealer handpiece. These factors contribute to the increased penetration ability of the irrigants into the apical and lateral canals [13]. Further, the flexible plastic-like points don't deform the canal walls like metal files in UIA, but as sonic devices operate at a lower level than ultrasonic devices, this may be linked to lower efficacy levels.

Despite the dentists' efforts to clean the root canal system and improve endodontic treatment outcomes, the optimal activation methods remain a challengeable question in the literature. Although there are some *in vitro* studies comparing both techniques and several systematic reviews about ultrasonic irrigant activation [3, 14–17], there is no meta-analysis comparing sonic and ultrasonic activation during endodontic treatment. Based on this, the current study was conducted to compare the root canal cleanliness, smear layer score, debris score, total amount of debris removed, penetration depths of irrigants and push-out bond strength values between sonic and ultrasonic activation during endodontic treatment.

Method

This meta-analysis was carried out following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines [18], and the recommendations of Cochrane collaboration [19]. The methodology of the study was documented in a protocol which was registered at http://www.crd.york.ac.uk/prospero/ (**Registration number**; CRD42020197779).

Pico question

Are sonic activation outcomes better than ultrasonic for endodontic treatment in human extracted teeth?

Data source

An extensive literature review was implemented, until 20 July 2020, by 2 independent reviewers, using the following databases; PubMed, Google Scholar, Web of Science (ISI), Scopus, SIGLE, Virtual Health Library (VHL), NYAM, Clinical trials, Controlled Trials (mRCT), EMBASE, WHO and International Clinical Trials Registry Platform (ICTRP). No restrictions were employed on patients' age, sex, ethnicity, language, race or place/region.

A further extensive search of each database using related articles function was carried out. Subsequently, manual scanning of references and bibliographies of all related studies was performed to retrieve all possible relevant articles that were not indexed. The cross-referencing approach was executed until no additional relevant articles were discovered.

Study selection

All *in vitro* and *ex vivo* studies comparing the outcomes of interest (total amount of debris removed, remaining debris scores, penetration depths of irrigants, total smear layer score, push-out bond strength values, percentage of canal cleanliness) between sonic and ultrasonic activation during endodontic treatment and reported at least one outcome of interest were included in the current meta-analysis. There was no restriction on the age or site of the extracted teeth. Studies including teeth with calcification, resorption, or cracks were ousted. Similar to that, non-comparative studies and studies in which data unattainable to be extracted, review articles, animal studies, case reports, comments, letters, editorials, posters, and book chapters were excluded. Taking into account that these outcomes are not possible to verify *in vivo*, only *in vitro* articles were included.

The screening process of the title, abstract, and the full text was performed independently to reveal the potentially relevant articles that met the inclusion criteria. The discussion dissolved the contradiction between the reviewers.

Data extraction and quality assessment

The following data (Table 1) were extracted from the finally included articles, independently by two reviewers (SP & LG): study characteristics (the title of the included study, the second name of the first author, year of publication, study design, study period, number of centres, and study region), teeth related data (number of teeth, age of patients, and source of the extracted teeth), endodontic treatment and root canal preparation (filling methods, irrigants, irrigation time, protocols of sonic and ultrasonic irrigation techniques, time of activation, and methods of outcomes assessment) and outcomes (total amount of debris removed, remaining debris scores, penetration depths of irrigants, total smear layer score, push-out bond strength values, percentage of canal cleanliness). The effect sizes were extracted from data reported as graphs using Web Plot Digitiser software (https://automeris.io/WebPlotDigitizer/).

The quality of the included studies was assessed based on the Checklist for Reporting *In Vitro* Studies (CRIS Guidelines) [20]and as demonstrated by Sarkis-Onofre *et al.,* 2014 [21], Moraes *et al.*, 2015 [22], and Valente *et al.*, 2016 [23] studies. The following parameters were put in consideration: sample size calculation, teeth randomisation, blinding of outcome assessment (detection bias), teeth free of caries or restoration, materials used according to the manufacturer's instructions, teeth with similar dimensions, endodontic treatment performed by a single operator, incomplete outcome data (attrition bias), and selective reporting (reporting bias), as seen in Figure 2. If the parameter was controlled, the domain was considered 'low risk 'and vice versa. If it was not reported, the domain was classified as 'unclear'.

Statistical analysis

Weighted mean difference (WMD) or standardised mean difference (SMD) was used for analysing the continuous variables. Mean and standard deviation (SD) were calculated from studies reported data using mean and range or median and range based on the equations exemplified by Hozo *et al.* [24]. The fixed-effect model was implemented when a fixed population effect size is assumed; otherwise, the random-effects model was used. Statistical heterogeneity was appreciated using Higgins I^2 statistic, at the value of $> 50\%$, and the Cochrane Q (Chi^2 test), at the value of $p < .10$ [25]. To account for this heterogeneity, the random-effects model was employed, and subgroup analysis was implemented concerning the anatomical considerations. Publication bias was assumed in the presence of an asymmetrical funnel plot and based on Egger's regression test (*p-value* <0.10). Herein, the trim and fill method of Duvall and Tweedie was used [26]. Data analysis was performed using Review Manager version 5.3 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark). The significant difference was established at the value of $p < .05$.

Results

The extensive literature review yielded an overall 365 articles. After duplicates removal, 224 reports were selected for title, abstract, and full-text screening. Amongst them, 16 articles were identified for review and meta-analysis besides three studies recognised throughout the manual search. A flow diagram illustrated the process of the literature search is shown in Figure 1.

Characteristics of the included studies

This meta-analysis included a total of 19 articles [3,4, 27–43]. These articles encompassed an overall 570 extracted teeth with an equal proportion of teeth (285 teeth) among sonic and ultrasonic groups. Regarding the studies distribution, six studies included teeth from Turkey, while three studies included extracted teeth from Indian patients. Out of the included studies, five and three studies included mandibular premolars and mandibular molars, respectively. Additionally, three studies included maxillary incisors. Having the sonic activation protocols, EndoActivator was employed among 15 studies whereby EDDY and Vibringe devices were implemented within two studies, separately. The irrigation time ranges from one to five minutes.

Apart from Weiss *et al.*, 2018 study, no study reported the method of sample size calculation, showing unclear risk of bias. All the included studies showed a low risk of bias regarding the teeth randomisation domain apart from Ackay *et al.*, 2016. Out of the included studies, 11 studies showed a low risk of detection bias whilst seven studies showed unclear risk of bias regarding materials used according to

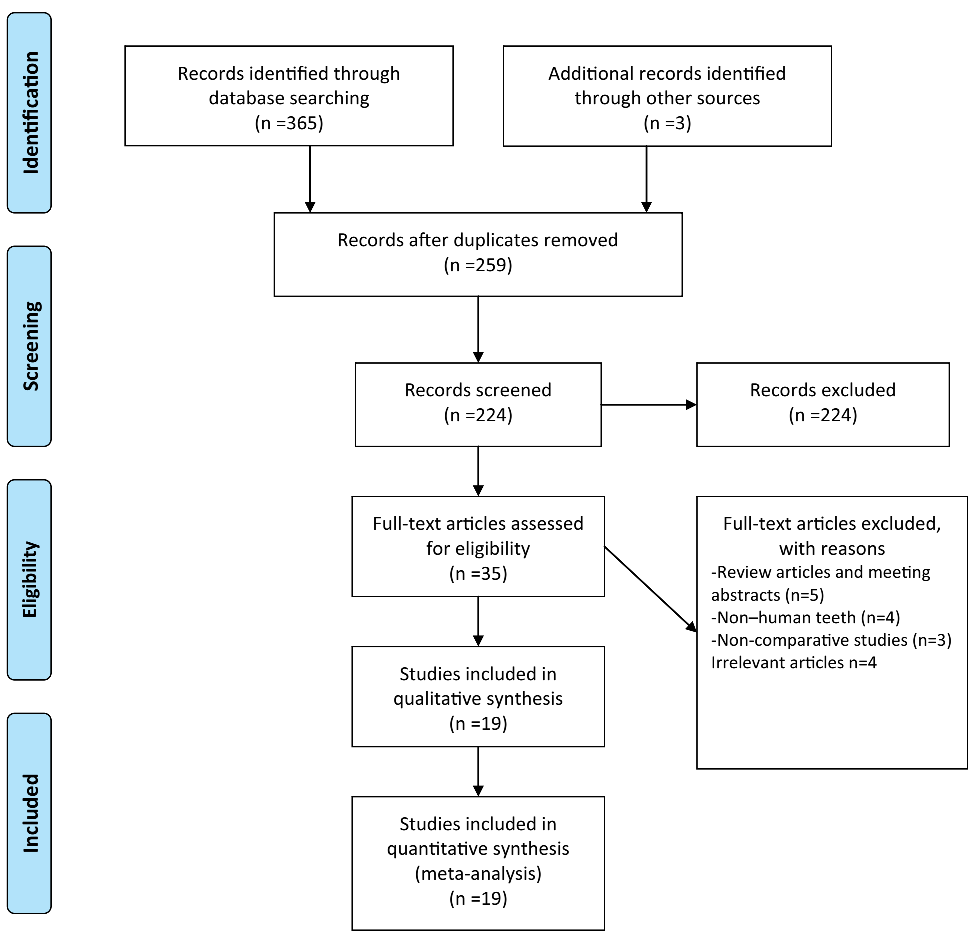

Figure 1. PRISMA Flow chart showing the process of the literature search, title, abstract, and full text screening, systematic review, and meta-analysis.

the manufacturer's instructions. Furthermore, 15 and five studies depicted low risk of bias regarding teeth with similar dimensions and endodontic treatment performed by a single operator domains, respectively. Only one study showed unclear risk of attribution and reporting biases.

Study endpoints

Amount of debris removed

Three studies, including 114 teeth, assessed the difference between sonic and ultrasonic irrigation regarding the mean amount of removed debris. In the random-effects model (I^2=91%, $p < .001$), pooling the data revealed no statistically significant difference between both groups (MD −0.00; 95%CI −0.71, 0.70; $p = 1.000$).

As for the change in root weight before and after irrigation, pooling two studies' effect sizes showed no statistically significant difference between sonic and ultrasonic irrigation (MD −0.12; 95%CI −0.59, 0.35; $p = .62$).

Mean debris scores

Two studies, including 54 teeth, evaluated the mean debris score between sonic and ultrasonic activation at the coronal level. In the random-effects model, there was no statistically significant difference between both groups (MD −0.00; 95%CI −0.24, 0.24; $p = 1.000$). At the middle level, pooling the data from two studies, including 64 extracted teeth, showed no statistically significant difference between sonic and ultrasonic activation (MD −0.23; 95%CI −0.72, 0.26; $p = .35$), as seen in Figure 3(A). At the apical level, there was no statistically significant difference between both groups (MD −0.00; 95%CI −0.24, 0.24; $p = 1.000$).

Mean smear layer scores

The mean smear layer score was reported within two studies, including a total of 64 extracted teeth. At the middle level, pooled analysis, in the random effects-model (I^2=78%, $p = .03$), showed no statistically significant difference between sonic and ultrasonic irrigation techniques (MD −0.34; 95%CI −0.92, 0.25; $p = .26$).

At the apical level, pooling the data in the random-effects model (I^2=64%, $p = .1$) revealed a statistically significant lower smear layer score within the sonic activation group, relative to the ultrasonically activated group (MD −0.48; 95%CI −0.92, −0.04; $p = .03$), as in Figure 3(B).

Percentage of canal cleanliness

Two studies, including 50 extracted teeth, assessed the percentage of canal cleanliness after sonic and ultrasonic activation. At one mm from the apex, there was no statistically significant difference between both groups (MD 0.46; 95%CI −2.32, 3.24; $p = .75$). In this concern, there was no statistically significant difference between sonically activated and ultrasonically activated teeth regarding the percentage of canal cleanliness at three mm (MD −0.36; 95%CI −1.83, 1.10; $p = .63$) and at five mm (MD −0.16; 95%CI −0.95, 0.62; $p = .68$) from the apex.

Irrigants penetration depth

The total irrigants penetration depth was assessed within four studies, including a total of 102 extracted teeth. Pooling the data revealed no statistically significant difference between sonically activated and ultrasonically activated teeth (MD −0.40; 95%CI −0.88, 0.09; $p = .11$), as seen in Figure 3 C.

At the coronal level, pooling the data in the random-effects model (I^2=78%, $p = .003$) showed no statistically significant difference between sonic and ultrasonic groups regarding the irrigants penetration depth (MD 0.01; 95%CI −0.85, 0.86; $p = .99$). In this respect, there was no statistically significant difference between sonically and ultrasonically activated groups regarding the irrigants penetration depth at the middle (MD −0.10; 95%CI −0.66, 0.46; $p = .73$) and apical levels (MD −0.40; 95%CI −0.99, 0.19; $p = .18$).

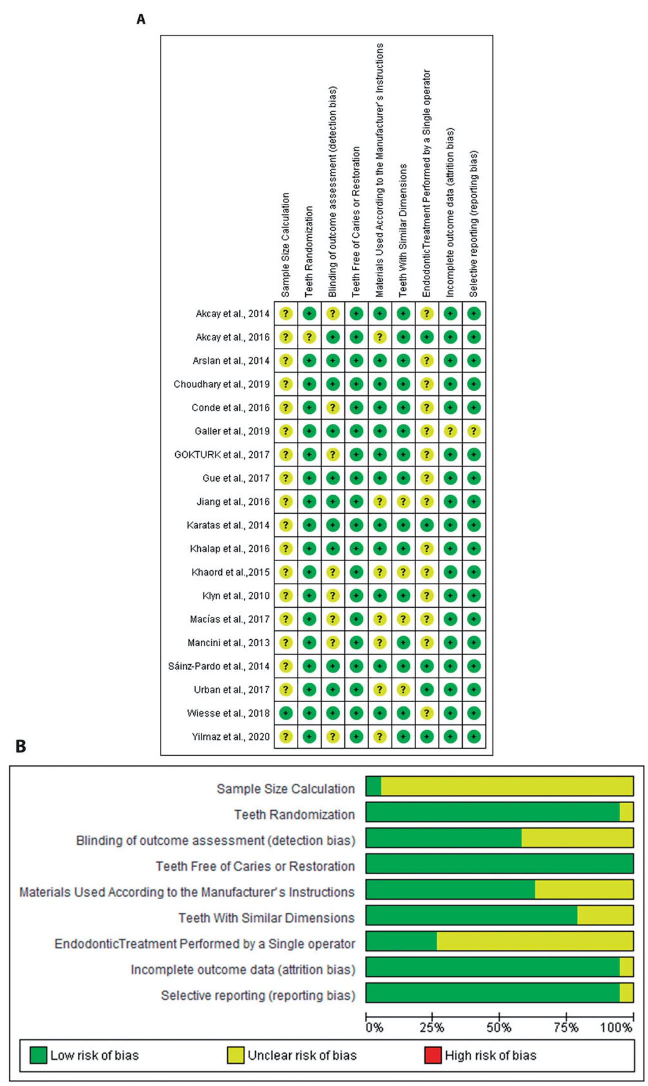

Figure 2. (A) Risk of bias summary: review authors' judgements about each risk of bias item for each included study. (B) Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

Push-out bond strength values

The mean push-out bond strength value was reported within two studies, including 62 extracted teeth. At the coronal level, pooling the data in the random-effects model (I^2=85%, *p* = .001) displayed no statistically significant difference between sonic and ultrasonic activation (MD −1.22; 95%CI −2.87, 0.44; *p* = .15).

In the random-effects model, pooling the data showed a statistically significant lower push-out bond strength value among the sonic activation group, in contrast to the ultrasonically activated group at the middle (MD −0.69; 95%CI −1.13, −0.25; *p* = .002) and at the apical levels (MD −0.78; 95%CI −1.09, −0.46; *p* < .0001), as in Figure 3(D-E).

Discussion

Irrigants penetration into a considerable area of the root canal system is a critical factor for successful endodontic therapy. It is essential to maximise the efficacy of irrigants penetration by combining solutions with different activation devices [44–46]. Being anatomically complex, finding the best agitation technique during root canal treatment is a doubtful question in the literature due to contradictory outcomes [47]. Therefore, this meta-analysis was conducted to reveal the outcomes of sonic and ultrasonic irrigations during endodontic treatment.

The evidence obtained in the current study showed that sonically activated teeth had a significantly lower smear layer

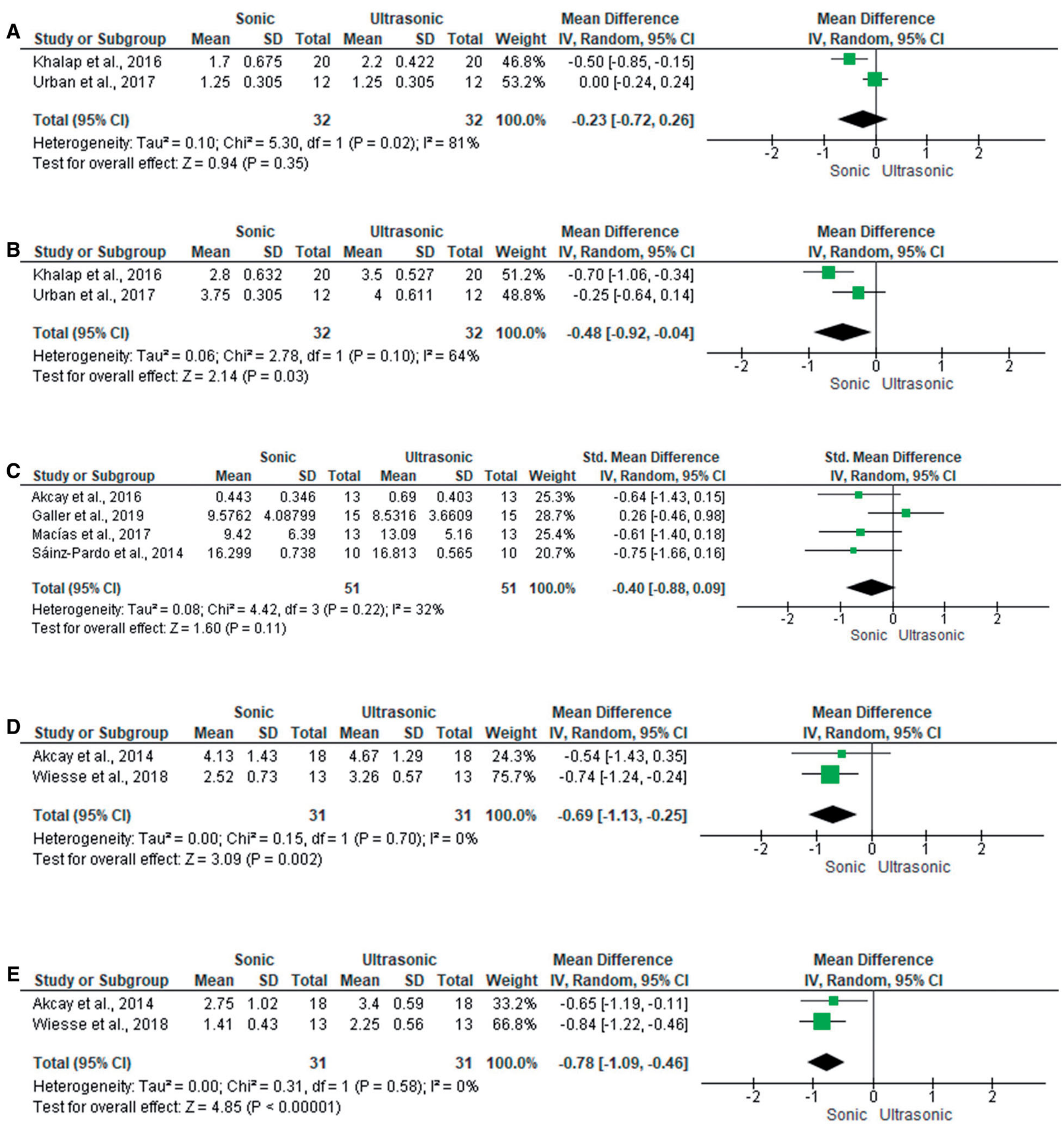

Figure 3. (A) Mean amount of removed debris. (B) Mean smear layer score at the apical level. (C) Total irrigants penetration depth. (D) Push-out bond strength value at the middle level (E) Push-out bond strength value at the apical level.

scores, particularly at the apical level of the root canal. On the contrary, root canals with irrigant solution ultrasonically activated had a remarkedly high push-out bond strength value. The push-out bond strength was measured between root canal sealers and root canal dentine. There was no superiority of either technique regarding the amount of removed debris, percentage of canal cleanliness, and irrigants penetration depth during endodontic therapy.

The apical third of the root canal has the utmost impact on the outcomes of endodontic therapy, being the communication part between periapical tissues and the pulp cavity [48]. In the present study, the employment of sonic activation during endodontic treatment decreased the smear layer score considerably at the apical level. As the lateral canals and ramifications are frequently presented in the apical region, their cleansing is crucial for effective endodontic treatment. In concordance with our findings, Shahravan *et al.*, 2017 stated that removing the smear layer noticeably improved the cleanliness and fluid-tight obturation of the root canal [49].

This finding might be attributed to the ineffective delivery of the irrigant solutions into the apical region of the root canal in the ultrasonically activated group. Additionally, the resultant acoustic microstreaming of the ultrasonic devices generates shear stress for dislodging debris from the operated canals. This mechanism produced unfavourable dampening alterations when the device tip comes in contact with the root canal's lateral walls, whereby sonic activation was not influenced by lateral wall contact as it uses less truculent tips [50–52].

According to the finding of the current study, UIA was more effective than sonic activation regarding the adhesion strength between the sealers and root dentine. This might be attributed to the high frequency and small oscillation amplitude of the ultrasonic devices, which generate adequate energy for the sealer for the more homogenous distribution [53]. Besides that, the generated heat from the previous process allows the better blending of the sealer particles and the root dentine, improving the cohesive strength between them [54]. The more the increase in the bond cohesion between the root dentine and the root canal sealer, the less the tendency of apical canal leakage. Such factors also keep the root canal sealer's position under different dislocating forces, such as the mechanical exertion of the operative procedures and tooth function. These factors impacted dramatically on the longevity of the endodontic treated root canals [55,56].

Regarding the root canal cleanliness, the current study showed no difference between sonically and ultrasonically activated groups, which was parallel with Silva *et al.*, 2019 study. Their systematic review announced that UIA achieved bacterial disinfection ability as non- activated irrigation [14].

This meta-analysis results should be interpreted cautiously due to the limitations in translating *in vitro* studies to *in vivo* circumstances. The included studies' sample size ranged from 14 to 60 teeth, which might impair the evidence. Additionally, there was significant heterogeneity among the included studies, stemming from difference in outcomes assessment methods, source of the extracted teeth, irrigant solutions, endodontic preparation, and activation protocols. Such heterogeneity was also statistically established for the employed random-effects model. Furthermore, the lack of optimal follow-up periods constringed the assessment of long-term outcomes.

Sonic activation accomplished advancement relative to ultrasonic agitation in removing the smear layer, mainly at the apical area, during endodontic therapy. Furthermore, ultrasonic activation of the irrigants resulted in significant cohesion between the sealers and the dentinal tubules, decreasing the vulnerability of apical leakage and tooth fracture. The integration of these findings in endodontic therapy protocols will help dentists to improve root canal therapy outcomes by stratifying the patients to the most appropriate and effective agitation technique. However, further randomised clinical trials are needed to address the limitations of the current meta-analysis, because it is hard to conclude by this research that one technique is better than the other.

Disclosure statement

The authors deny any conflicts of interest.

Funding

FCT/MCTES – Portuguese Foundation for Science and Technology within the scope of the project UIDB/50006/2020.

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