Research Article ISSN 2639-9490

Oral Health & Dental Science

Efficacy of Sonic Versus Ultrasonic Irrigation in Debris Removal from the Root Canal System: A Systematic Review

Kenza ABOUZAID, DDS, and Said DHAIMY, DDS, MSc, PhD*

Department of restorative dentistry and Endodontics, school of dentistry, University Hassan II, Casablanca - Morocco

***Correspondence:**
Said DHAIMY, DDS, MSc, PhD, Professor of Department of restorative dentistry and Endodontics, School of Dentistry, Hassan II university, Abou Al Alaa Zahar Street 21100, Mers Sultan, Casablanca, Morocco, Tel: +212662032510, ORCID ID: 0000-0002-7846-6228.

Received: 17 August 2021; **Accepted:** 12 September 2021

Citation: ABOUZAID K, DHAIMY S. Efficacy of Sonic Versus Ultrasonic Irrigation in Debris Removal from the Root Canal System: A Systematic Review. Oral Health Dental Sci. 2021; 5(3); 1-13.

ABSTRACT

Introduction: *The aim of this study was to systematically review the debridement efficacy of ultrasonic irrigation compared with sonic irrigation during the endodontic treatment.*

Methods: *An electronic search was undertaken on Cochrane Library, Medline, ScienceDirect and Scopus for articles published between January 2010 and January 2021 using appropriate Mesh terms and key words. The inclusion criteria were systematic reviews or in vitro controlled trials on permanent mature teeth or models simulating the root canal system involving a sonic or ultrasonic irrigation group and a control group of conventional needle irrigation. Two reviewers independently selected articles to include according to the inclusion criteria, extracted data from the articles and assessed the methodological quality of the included studies. The data items were arranged in tables.*

Results: *From 811 studies, 17 in vitro studies and 3 systematic reviews were included. EndoActivator and EDDY were the most sonic devices used, whereas several ultrasonic devices were tested for passive ultrasonic irrigation. Debris removal was assessed either on root canal walls or isthmuses or both. The risk of bias and quality of the selected studies were qualified as moderate to high according to the JBI (Joanna Briggs Institute) and the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) checklists. Overall, the findings confirmed superiority of the two agitation techniques over conventional irrigation and most of the studies showed no significant differences between sonic and ultrasonic irrigation in debris removal, however a moderate level of evidence showed superiority of ultrasonic irrigation.*

Conclusion: *It may be concluded that sonic and ultrasonic activation of the irrigants are beneficial in hard tissue debris removal when compared to conventional needle irrigation, yet, the current data could not find significant differences between the two techniques.*

Keywords
Passive ultrasonic irrigation, Sonic irrigation, Debris removal, Sodium hypochlorite.

Introduction
The aim of every endodontic treatment is the elimination of the microbial infection within the root canal and preventing its re-infection. This requires the cleaning and shaping of the root canal system through instrumentation [1]. However, one of the side effects of shaping is the generation and accumulation of hard tissue debris [2] especially in areas remaining uninstrumented during the root canal preparation such as accessory canals, isthmuses and

ramifications [3]. Hard tissue debris are bacteria's shelters and can also interfere with the adhesion of the root canal filling materials and therefore avoid reaching a three-dimensional obturation of the root canal system [2], which may cause the persistence of the infection and the failure of the root canal treatment.

A final irrigation is a must in the root canal treatment in order to eliminate hard tissue debris [4]. Sodium hypochlorite (NaOCl) is the most endodontic irrigant used for its antibacterial properties and its ability to dissolve organic tissues [5]. However, it is unable to remove the inorganic components, which justifies the use of chelator agents like Ethylene diamine tetra acetic acid (EDTA) in combination with NaOCl [6].

The delivery of the irrigants was conventionally realized with a syringe and needle, this technique is still accepted but seems to be insufficient to remove hard tissue debris from areas hard to reach [7]. In fact, the irrigant has a limited effect beyond the tip of the needle and a low velocity [8]. Therefore, several mechanical agitation techniques have been developed in order to improve the root canal cleaning and disinfection, and have shown better results than syringe irrigation, mainly Passive ultrasonic irrigation (PUI) and Sonic irrigation (SI) [9]. Ultrasounds in final irrigation are used in a range of frequencies between 25 and 40 KHz [6], and generate acoustic streaming as described by Ahmad [10], producing thereby shear forces which enhances debridment. Sonic irrigation operates at lower frequencies (190-6000Hz) using polymer tips to prevent an over-instrumentation of the root canal wall [11]. Previously published systematic reviews [12,13] have assessed the efficacy of mechanical agitation techniques on the hard tissue debris removal compared to conventional syringe irrigation, however, none of them allowed a comparison between passive ultrasonic irrigation and sonic irrigation. Therefore, the aim of our study was to systematically review and critically analyze the evidence on the cleaning and debridement efficacy when passive ultrasonic irrigation is used compared to sonic irrigation.

Materials and Methods

The following systematic review was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [14] guidelines.

Protocol and registration

This systematic review was done according to PRISMA guidelines and was previously published on Open Source Framework. Link to the protocol: https://osf.io/p6xz8.

PICOS Question

The research question was formulated based on PICOS (Population, intervention, comparison, outcomes and study design) format: "Does Passive Ultrasonic Irrigation result in better hard tissue debris removal when compared to Sonic Irrigation in mature permanent teeth from controlled trials and systematic reviews?"

- *Population:* Mature Permanent teeth.
- *Intervention:* Passive ultrasonic irrigation and Sonic irrigation.
- *Comparison:* Conventional needle irrigation.
- *Outcomes:* Hard tissue debris removal.
- *Study design:* Controlled trials and Systematic Review on controlled trials.

Eligibility criteria

Studies that met all the following inclusion criteria based on the PICOS question were included in the review:

- Systematic reviews or in vitro controlled trials performed on mature permanent teeth without any anterior root canal treatment.
- Systematic reviews or in vitro controlled trials performed using models simulating the root canal system.
- Studies evaluating passive ultrasonic irrigation to another irrigation technique in hard tissue debris removal.
- Studies evaluating sonic irrigation to another irrigation technique in hard tissue debris removal.

Studies that met any of the following exclusion criteria were excluded:

- Studies that performed activation of the irrigation on teeth with root caries, resorption, fractures or fractured instruments within the canal.
- Studies not evaluating hard tissue debris removal.
- Studies using irrigants other than sodium hypochlorite and EDTA.
- Not standardized instrumentation in the compared groups.
- Studies not including a Passive Ultrasonic Irrigation or Sonic Irrigation group.
- Studies not including a conventional needle irrigation group as the control.

The research included all the studies published between January 2010 and January 2021. Only publications in English and those with translations available in English were selected.

Information Sources

An electronic search strategy was conducted for eligible literature from January 2010 to January 2021 on 4 data-bases: Medline trough PubMed interface, ScienceDirect, Scopus and Cochrane Library.

Search

Appropriate key words and Mesh terms; "therapeutic irrigation", "root canal preparation", "sodium hypochlorite", "ultrasonic therapy", "sonication", "root canal irrigants", "therapeutic irrigation", "sonic agitation", "ultrasonic agitation", "root canal irrigation", "sonic activation" and "ultrasonic activation", were selected from articles published in endodontic journals and were used in a series of combinations repeated each time in the 4 data bases. The search on ScienceDirect was restricted to Review articles and research articles.

The electronic search strategy is shown in Table 1.

Study selection

Duplicates were removed and two reviewers screened titles and abstracts (and the full-text copy in cases where abstracts were not

Table 1: Electronic Search Strategy on Medline, ScienceDirect, Scopus and Cochrane Library.

	Search strategy	Results			
		PubMed	ScienceDirect	Scopus	Cochrane
#1	"Therapeutic Irrigation/instrumentation" [Mesh] OR "Therapeutic Irrigation/methods" [Mesh] AND ("Root Canal Preparation/instrumentation" [Mesh] OR "Root Canal Preparation / methods" [Mesh]) AND "Sodium Hypochlorite" [Mesh]) AND "Ultrasonic Therapy" [Mesh]	19	92	14	17
#2	(("Sonication"[Mesh]) AND "Ultrasonic Therapy"[Mesh]) AND " Root Canal Irrigants" [Mesh]	5	54	7	1
#3	(("Sonication" [Mesh]) AND "Ultrasonics"[Mesh]) AND "Root Canal Irrigants" [Mesh]	14	140	24	4
#4	(("Sonication"[Mesh]) AND "Ultrasonic Therapy"[Mesh]) AND "Therapeutic Irrigation"[Mesh]	6	38	8	1
#5	"Sonic agitation" AND "Ultrasonic agitation" AND "Root canal irrigation"	40	91	1	0
#6	"Sonic activation" AND "Ultrasonic activation" AND "Root canal Irrigation"	82	135	18	0

available) independently and selected *in vitro* controlled trials which applied passive ultrasonic irrigation or sonic irrigation and excluded off-topic articles that didn't meet the inclusion criteria. In case of doubt or disagreement, the studies were included and the full-texts were assessed for eligibility in the next step. The full texts of the remaining titles were obtained and were evaluated. Studies were included if they met all the inclusion criteria based on the PICOS question. Studies that met any of the following exclusion criteria were excluded.

Data collection process

Pre-determined data were extracted in duplicate from the included studies by the two reviewers for evidence synthesis and quality assessment. Data were arranged in data tables.

Data items

The following data were extracted:

1. First author name and year of publication.
2. Study design.
3. Sample size (total and per group).
4. Type of samples used.
5. Apical size, taper and if the system was closed.
6. Irrigant solutions used and volume.
7. Devices tested, controls used, power setting/frequency and depth from the working length.
8. Area and method of assessment.
9. Randomization and blinding if applicable.
10. Statistical methods adopted and main outcomes.

Quality assessment and risk of Bias in individual studies

Validity of the included trials and systematic reviews was assessed based on the CON-Solidated Standards of Reporting Trials (CONSORT) [15] and Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [14], respectively. Furthermore, methodological quality of the studies was evaluated according to the Joanna Briggs Institute (JBI) clinical appraisal Checklist. The critical appraisal tool was adapted to *in vitro* trials as it was described in a previously published study [16].

The risk of bias was assessed independently by the reviewers. Studies were judged with a low methodologic quality if they had a score of 1, 2 or 3 points, moderate methodologic quality if they had a score of 4, 5 or 6 points and a high methodologic quality if they had a score of 7, 8 or 9 points (Table 2).

Table 2: Joanne Briggs Institute critical appraisal.

	Yes	No	Unclear
1. Was true randomization used for assignment of participants to treatment groups?			
2. Was allocation to treatment groups concealed?			
3. Were treatment groups similar at the baseline?			
4. Were those delivering treatment blind to treatment assignment?			
5. Were outcomes assessors blind to treatment assignment?			
6. Were treatment groups treated identically other than the intervention of interest?			
7. Were outcomes measured in the same way for treatment groups?			
8. Were outcomes measured in a reliable way?			
9. Was appropriate statistical analysis used?			

The methodological quality of the systematic reviews included was assessed following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [14]. Studies were judged with a low methodologic quality if they had a score between 1 and 9 points, moderate methodologic quality if they had a score between 10 and 18 points and a high methodologic quality if they had a score between 19 and 27 points.

The quality of the studies was assessed independently by two reviewers. In case of disagreement, it was solved through discussion between them.

Results

The included studies are heterogenous because of the large variability of the systems being employed and the different protocols. Hence, a quantitative synthesis is not feasible. A narrative synthesis of the available findings was conducted instead.

Study selection

The electronic search resulted in 811 titles, 497 were removed due to duplications. The remaining 314 were screened according to the titles and the abstracts for eligibility and 272 studies were excluded. The publications ranged from January 2010 to January 2021 except one study that dates from 2003. 42 titles were then eligible for full text evaluation by at least one reviewer. 22 studies

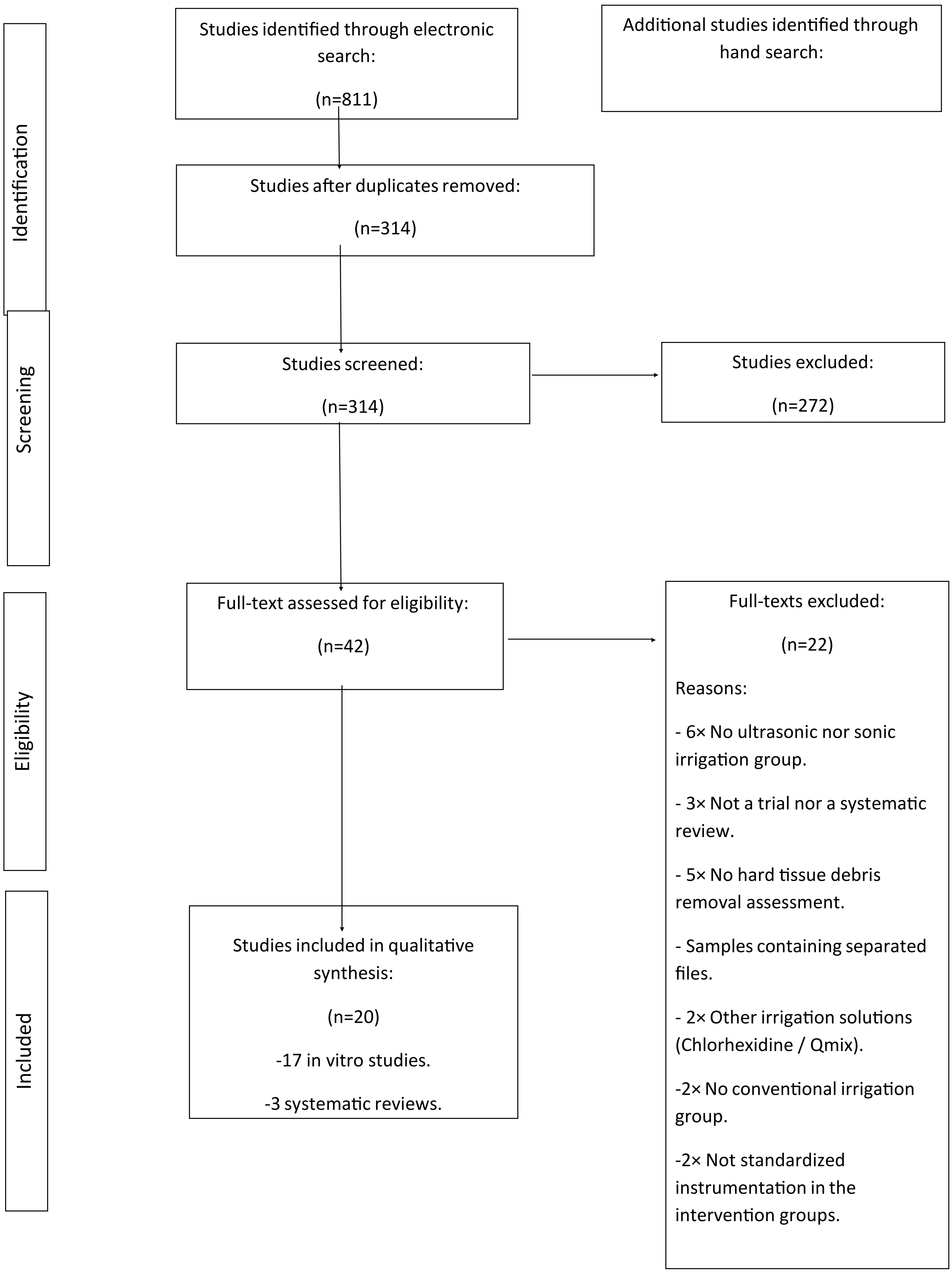

Figure 1: PRISMA flow diagram.

did not meet the inclusion criteria and were excluded. Reasons for exclusion are presented in Figure 1. Finally, 20 studies were selected for the qualitative synthesis including 17 *in vitro* studies and 3 systematic reviews. All the included articles were written in English.

Study characteristics

All samples used were extracted human teeth and none of the included studies used a model simulating the root canal system. Two articles did not mention the type of the teeth included in the experiment [24,26]. Six studies included teeth with curved root

Table 3: Study details of articles included in data synthesis. SEM, Scanning electron microscope; Micro-CT, Micro-computed tomography.

Study	Sample size	Sample	Apical size/ Taper	Apex	Area of interest	Assessment
Sabins et al. 2003 [17]	100	Extracted molars	35/-	Open system	The area between 0-3mm and 3-6mm from the apex	Mean percentage of remaining debris calculated on root halves photographs analysed with Adobe Photoshop 5.0 software and enlarged to 100×.
Kanter et al. 2011 [18]	75	Extracted maxillary canines	40/06	Open system	3 and 5 mm from the apex	Qualitative assessment of tubules using a graded scale of 0 to 2 on photographs under SEM 500×.
Linden et al. 2020 [19]	27	Extracted mandibular molars containing a root with 2 canals connected by a large isthmus	30/07	Closed system with acrylic resin	Mesial root canal and isthmus	Micro-CT scanning was performed to assess the volume of hard tissue debris.
Urban et al. 2017 [20]	58	Extracted mandibular premolars	40/06	Closed system with wax	Coronal, middle and apical portions of one-half split root canal	Photomicrographs were assessed for remaining debris under SEM evaluation at 200× magnification following a score system of 1 to 5.
Duque et al. 2016 [21]	50	Mesial roots of extracted mandibular molars with curvature not exceeding 5°	35/04	Closed system with epoxy resin	Mesiobuccal, mesiolingual canals and isthmus at 2,4 and 6mm from the apex	SEM images were taken after instrumentation, first, second and third activation of the irrigant and assessed for remaining debris using the Image J Software.
Amato et al. 2011 [22]	12	6 single-rooted premolars with straight root canals. 6 curved molars with curvature ranging between 17° and 27°	45/-	Close system using an impression material	Canal wall and 3 depressions of 0,3mm in diameter and 0,5mm in depth cut into the wall of one root half at 2, 4 and 6mm from the apex. The depressions were filled with dentine debris.	Images of the root canal walls were taken using a digital camera connected to a microscope at a magnification of 8× and 20×. The amount of the remaining debris was scored from 0 to 3.
Haupt et al. 2019 [23]	90	Mesiobuccal root canals of extracted mandibular molars with a curvature between 20 and 40°	40/04	Closed system with sticky wax	One area of the apical and coronal region chosen randomly of each root canal half	The presence of remaining debris was scored using a 5- grade scoring system under SEM at 200× magnification.
Castagnola et al. 2014 [24]	80	Single rooted extracted teeth	40/06	Closed system with silicone	The coronal, middle and apical regions of the root canals halves.	The amount of remaining debris was scored from 1 to 4 under SEM at 700× magnification.
Jiang et al. 2010 [25]	18	Extracted maxillary canines with straight root canals	30/06	Closed system with self-curing resin	A groove cut in the wall of each half root canal of 4 mm length, 0,5 mm deep and 0,2 mm wide at 2-6 mm from the WL. Each groove was previously filled with dentin debris.	The amount of remaining dentin debris in the grooves was scored under SEM on a scale from 0 to 3.
Plotino et al. 2020 [26]	70	Extracted teeth with only one rounded root canal and moderate curvatures (<10°)	40/06	Closed system with siloxane putty material	Coronal, middle and apical areas of the two halves of each root canal previously split longitudinally in the buccolingual direction.	The presence of debris on the root canal wall was scored from 1 to 4 under SEM at a magnification of 1000×
Rödig et al. 2010 [27]	80	Mesiobuccal root canals of extracted mandibular molars with a curvature less than 20°	40/02	Closed system with sticky wax	Coronal and apical region of the two halves of each root canal previously split longitudinally in the buccolingual direction.	The amount of remaining debris was scored under SEM at 200× on a scale from 1 to 5
Klyn et al. 2010 [28]	40	Mesial roots of extracted mandibular molars with a curvature less than 25°	40/04	Closed system with Triad Gel	Three horizontal sections at 1, 3 and 5 mm from the apex. The assessment Was performed at the root canals and the isthmus.	Images of the coronal aspect of each section were made by using a digital camera attached to a stereomicroscope at the highest magnification. Software Image J was used to calculate the percentage of debris present.

Malki et al. 2012 [29]	15	Extracted maxillary canines with straight roots.	35/04	Closed system with rubber dam caulk	4 depressions of 0.3mm diameter located at 2,4 and 6 mm from the WL were created in the wall of one half of each root canal previously biscected longitudinally.	Before and after each irrigation procedure, the root halves were separated and the depressions were viewed through stereomicroscope. Picture were taken, and the samples were graded as "clean" or "not clean".
Rödig et al. 2019 [30]	40	Mesial roots of extracted mandibular molars with moderately curved root canals ranging from 10 to 25° and a radius between 5.5 and 16.5 mm	25/08	Closed system with resin	Root canals and isthmus	Pre and post-operative scans using Micro-CT were performed, and the percentage of hard tissue debris was quantified.
Deleu et al. 2013 [31]	25	Straight roots from extracted maxillary canines	30/06	Closed apex with acrylic	A groove of 4 mm length, 0,5mm in deep and 0,2mm in wide was created at 1mm from the WL in the wall of one half of each root canal previously split longitudinally. The grooves were filled with dentine debris.	The amount of present debris was scored from 0 to 3 using a digital camera mounted on a microscope at 13,6×
Thomas et al. 2014 [32]	64	Mesial roots of extracted mandibular molars with canal isthmus	40/06	Closed apex using clear acrylic resin	Isthmus area from horizontal sections (2mm thick) at 2 and 4mm from the apex	Specimens were viewed under stereomicroscope at 200× and the isthmus region was photographed before and after shaping and after final irrigation. Image J software was used to compare photographs and calculate the percentage reduction of debris.
Jiang et al. 2010 [33]	20	Extracted maxillary canines with straight root	30/06	Closed system with self-curing resin	A groove of 4 mm length, 0,5mm in deep and 0,2mm in wide was created at 2mm from the WL in the wall of one half of each root canal previously split longitudinally. The grooves were filled with dentine debris.	The grooves were viewed through stereomicroscope and remaining debris were scored from 0 to 3.

Table 4: Characteristics of Use for Conventional Needle Irrigation. NaOCl, Sodium hypochlorite; EDTA, Ethylene diamine tetra acetic acid.

Study	Needle	End type	Gauge	Irrigant/Volume	Depth from the WL	Time
Sabins et al. 2003 [17]	Monoject	Slotted	27	NaOCl (5,25%)/5ml	Deep without binding	-
Kanter et al. 2011 [18]	Max-i-probe	Slotted	28	NaOCl (6,15%)/1ml EDTA (17%)/1ml	1 mm	60 sec
Linden et al. 2020 [19]	Appli-Vac	Notched	30	NaOCl (2,5%)/3ml	2 mm	-
Urban et al. 2017 [20]	NaviTip	Open-ended	30	NaOCl (3%)/12ml	1mm	90 sec
Duque et al. 2016 [21]	NaviTip	-	30	NaOCl (2,5%)/6ml	2mm	3 cycles of 20 seconds
Amato et al. 2011 [22]	Max-I-Prob	Side-vented	30	NaOCl (1%)/6ml	1mm	-
Haupt et al. 2019 [23]	NaviTip	-	30	NaOCl (3%)/6ml	Deep without binding, but not more than 1mm from the WL	3 cycles of 20 seconds
Castagnola et al. 2014 [24]	NaviTip	-	30	NaCl (5,25%)/5ml EDTA (17%)/5ml	2mm	3 min
Jiang et al./ 2010 [25]	-	-	30	NaOCl (2%)/6ml Water/6ml	1mm	3 cycles of 20 seconds
Plotino et al. 2020 [26]	NaviTip	-	30	NaOCl (5%)/4ml EDTA (17%)/5ml Distilled water/5ml	Until reaching the WL	80 sec 2 min 2 min
Rödig et al. 2010 [27]	NaviTip	-	30	NaOCl (3%)/5ml EDTA (17%)/5ml	1mm	-
Klyn et al. 2010 [28]	Max-i-Prob	-	30	NaOCl (6%)/1ml	1mm	-
Malki et al./ 2012 [29]	NaviTip	-	30	NaOCl (2%)/2ml	1mm	10 sec
Rödig et al./ 2019 [30]	Endo-EZE	-	30	NaOCl (1%)/5ml EDTA (15%)/5ml	2mm	4 cycles of 20 seconds
Deleu et al./ 2013 [31]	Monoject	-	27	NaOCl (2,5%)/4ml	1mm	Approximatively 14 sec
Thomas et al./ 2014 [32]	Max-I-Prob	Side-vented	-	NaOCl (5,25%) / 4ml EDTA (17%) / 4ml NaOCl (5,25%) / 4ml	- - -	30 sec 30 sec 30 sec
Jiang et al./ 2010 [33]	NaviTip	-	30	NaOCl (2%) /2ml	1mm	-

Table 5: Characteristics of Use for Sonic Irrigation.

Study	Irrigant/Volume	Device	Power setting/ Frequency	Tip/Taper	Depth from the WL	Agitation time
Sabins et al./ 2003 [17]	NaOCl (5,25%)/5ml	MM 1500 sonic handpiece	1500Hz	Rispisonic size 1	2mm	30 sec 60 sec
Kanter et al./ 2011 [18]	NaOCl (6,15%)/1ml EDTA (17%)/1ml	EndoActivator	Manufacturer's recommendations	-	-	60 sec
Linden et al./ 2020 [19]	NaOCl (2,5%)/3ml	VDW GmbH	6kHz	EDDY 25/04	2mm	3 cycles of 20 seconds
Urban et al. 2017 [20]	NaOCl (3%)/12ml	EndoActivator - 	166 Hz 60000Hz	24/04 polymer tip EDDY 25/04	1mm	3 cycles of 30 seconds
Duque et al. 2016 [21]	NaOCl (2,5%)/6ml	EndoActivator	-	25/04 polymer tip	2mm	3 cycles of 20 seconds
Haupt et al. 2019 [23]	NaOCl (3%)/6ml	EndoActivator Proxeo ZA 55 Lm	10000 cpm 5000Hz	Polymer tip 25/04 EDDY	Deep without binding, but not more than 1mm from the WL	3 cycles of 20 seconds
Castagnola et al. 2014 [24]	NaOCl (5,25%)/5ml EDTA (17%)/5ml	EndoActivator	-	25/04 polymer tip	2mm	3min
Jiang et al. 2010 [25]	NaOCl (2%)/6ml Water/6ml	EndoActivator	190 190 160 190	15/02 polymer tip 25/04 polymer tip 15/02 polymer tip 15/02 polymer tip	1mm	3 cycles of 20 seconds
Plotino et al.2020 [26]	NaOCl (5%)/3ml NaOCl (5%)/1ml EDTA (17%)/5ml Distilled water/5ml NaOCl (5%)/3ml NaOCl (5%)/1ml EDTA (17%)/5ml Distilled water/5ml	EndoActivator Not activated Not activated Not activated Air-scaler (W&H) Not activated Not activated Not activated	- Power 1	25/04 polymer tip EDDY	1mm 1mm	3 cycles of 20 seconds 20 sec 2 min 2min 3 cycles of 20 seconds 20 sec 2 min 2min
Rödig et al. 2010 [27]	NaOCl (3%)/5ml EDTA (17%)/5ml	EndoActivator	10000 cpm	25/04 polymer tip	2mm	1min 1min
Klyn et al. 2010 [28]	NaOCl (6%)/2ml	EndoActivator	10000 cpm	15/02 polymer tip	2mm	30 sec
Rödig et al. 2019 [30]	NaOCl (1%)/5ml EDTA (15%)/5ml NaOCl (1%)/5ml EDTA (15%)/5ml	EndoActivator Sonic Flex	166 Hz 6000Hz	15/02 polymer tip EDDY 25/06	2mm 2mm	4 cycles of 20 seconds 4cycles of 20 seconds

Table 6: Characteristics of Use for Ultrasonic Irrigation.

Study	Irrigant/Volume	Device	Power setting or Frequency	File Size/ Taper	Depth from the WL	Activation time
Sabins et al. 2003 [17]	NaOCl (5,25%)/ 5ml	Mini-endo	Manufacturer's recommended power setting	#15 ultrasonic file	2mm	30 sec 60 sec
Kanter et al. 2011 [18]	NaOCl (6,15%)/1ml EDTA (17%)/1ml	Suprasson P5 Newtron	Power setting 6	K 15	1mm	60 sec
Linden et al. 2020 [19]	NaOCl (2,5%)/3ml	Suprasson Pmax Newtron	45% of the maximum power ('Yellow 9')	Irrisafe 20/-	2mm	3 cycles of 20 seconds
Urban et al. 2017 [20]	NaOCl (3%)/12ml	VDW-Ultra	30 kHz	Irri S 25/00	1mm	3 cycles of 30 seconds
Duque et al. 2016 [21]	NaOCl (2,5%)/6ml	Ultrasound Unit Gnatus	Power setting 2	Irrisonic 20/01	2mm	3 cycles of 20 seconds
Amato et al. 2011 [22]	NaOCl (1%)/6ml	-	-	Endo Soft Instrument	1mm	60 sec
Haupt et al. 2019 [23]	NaOCl (3%)/6ml	Piezo Smart	30 kHz	K-file 15/-	Deep without binding, but not more than 1mm from the WL. The file was pre-bent according to the curvature.	3 cycles of 20 seconds
Jiang et al. 2010 [25]	NaOCl (2%)/6ml	Suprasson PMax	30 kHz	IrriSafe 20/00	1mm	3 cycles of 20 seconds

Plotino et al. 2020 [26]	NaOCl (5%)/3ml NaOCl (5%)/1ml EDTA (17%)/5ml Distilled water/5ml	VDW. Ultra Not activated Not activated Not activated	Power setting 30 - - -	IRRI S 25/25 - - -	1mm - - -	3 cycles of 20 seconds - - -
Rödig et al. 2010 [27]	NaOCl (3%)/5ml EDTA (17%)/5ml	Piezo Smart	Power set at ¼ of the scale	K-type 15/02	2mm	1min 1min
Klyn et al. 2010 [28]	NaOCl (6%)/2ml	An ultrasonic unit	Setting at low power	30K PEC Endosonic size 20/-	-	30 sec
Malki et al. 2012 [29]	NaOCl (2%)/2ml NaOCl (2%)/2ml NaOCl (2%)/2ml NaOCl (2%)/2ml NaOCl (2%)/2ml	Suprasson PMax Suprasson PMax Suprasson PMax Suprasson PMax Suprasson PMax	30kHz 30kHz 30kHz 30kHz 30kHz	IrriSafe 20/00 IrriSafe 20/00 IrriSafe 20/00 IrriSafe 20/00 IrriSafe 20/00	1mm 2mm 3mm 4mm 5mm	10 sec 10 sec 10 sec 10 sec 10 sec
Rödig et al. 2019 [30]	NaOCl (1%) /5ml EDTA (15%) /5ml	VDW Ultra	Power setting at 30%	IRRI S 25/00	2mm	4 cycles of 20 seconds
Deleu et al. 2013 [31]	NaOCl (2,5%) /4ml	Suprasson PMax	Power setting at 50%	IrriSafe 20/00	1mm	20 sec
Thomas et al. 2014 [32]	NaOCl (5,25%) / 4ml EDTA (17%) / 4ml NaOCl (5,25%) / 4ml	-	Power setting of 5	Irrisafe tip -/-	2 and 4mm moved in an up and down motion	30 sec 30 sec 30 sec
Jiang et al. 2010 [33]	NaOCl (2%)/2ml NaOCl (2%)/2ml	Suprasson PMax Newtron Suprasson PMax Newtron	Power setting "blue 4" Power setting "blue 4"	Irrisafe 20/00 (with the oscillation perpendicular to the groove) Irrisafe 20/00 (with the oscillation toward the groove)	1mm 1mm	10 sec 10 sec

Table 7: Outcomes. PUI, Passive ultrasonic irrigation; SI, Sonic irrigation; SNI, Syringe and needle irrigation.

Study	Intervention groups	Control	Main Outcomes
Sabins et al. 2003 [17]	MM 1500 Sonic handpiece Mini-Endo	Monoject	PUI and SI for as little as 30 sec resulted in significantly less dentin debris in comparison with SNI at both regions. Moreover, PUI performed significantly better than SI at both regions. There was no significant difference between 30 and 60 seconds for either method.
Kanter et al. 2011 [18]	EndoActivator Suprasson P5 Newtron	Max-i-probe	EA produced more open tubules at all levels and removed significantly more debris than PUI at 3mm, while no statistical difference was shown at 5 mm between the two devices.
Linden et al. 2020 [19]	EDDY Irrisafe	Appli-Vac	Percentage reduction of debris in PUI group (66,8%) was significantly higher than in SI group (36,4%), while percentage of debris reduction in SNI (43,7%) did not statistically differ from PUI and SI groups.
Urban et al. 2017 [20]	EndoActivator EDDY Irri S	Navi-Tip Negative Control (no irrigation)	SNI removed significantly less debris than the other groups. Further significant differences between groups were not obtained.
Duque et al. 2016 [21]	EndoActivator Irrisonic	NaviTip	-Isthmus: None of the systems could completely eliminate debris, however, the amount of debris decreased while increasing agitation steps. Also, PUI was more efficient than SNI at 6 mm, but did not statistically differ from EndoActivator. -Canals: at 6 mm PUI was able to completely eliminate debris after the 3 agitation steps in some specimens. At the end of every procedure, PUI and the EndoActivator presented no statistical differences.
Amato et al. 2011 [22]	RinsEndo Endo Soft Instrument	Max-I-Prob	In straight root canals: PUI showed a high effectiveness in debris removal from the root canal walls and the depressions and could accomplish complete debris removal in all cases. In curved root canal: PUI showed a lower efficacy compared with the straight root canals, and showed no statistical difference with SNI.
Haupt et al. 2019 [23]	EndoActivator EDDY Proxeo ZA 55 Lm	NaviTip Control group (without irrigation)	The EndoActivator group showed 87% of clean surfaces, followed by EDDY with 80%, PUI with 72.5% and SNI with 55%. Moreover, the EndoActivator and EDDY performed significantly better than SNI, but without significant difference to PUI.
Castagnola et al. 2014 [24]	EndoActivator EndoVac	NaviTip (NaOCl) Saline	The EndoActivator performed better than the conventional irrigation in all canal areas, whereas no samples of the conventional irrigation group showed a complete clean root canal. Also, conventional irrigation removed significantly more debris from the coronal and middle thirds than the apical third while no statistically significant differences were found among the coronal, middle and apical thirds in the EndoActivator group.
Jiang et al. 2010 [25]	EndoActivator Suprasson PMax	Syringe and needle	Significantly more dentin debris were removed in the intervention groups than in the control. PUI was significantly more efficient than SI with 90% of completely clean samples, whereas there was no significant difference among the SI groups.

Plotino et al. 2020 [26]	EndoActivator (In conventional irrigation) EndoActivator (In stepwise intraoperative activation) EDDY (In conventional irrigation) EDDY (In stepwise intraoperative activation) VDW. Ultra (In conventional irrigation) VDW. Ultra (In stepwise intraoperative activation)	NaviTip	All the activation groups performed better than the control except for the EndoActivator in conventional irrigation at the apical third. In the apical third: PUI and EDDY groups removed significantly more dentin debris than EndoActivator group, with no significant difference between PUI and EDDY; In the middle third: PUI removed significantly more dentine debris than EndoActivator and EDDY, with no significant difference between these latter. In the apical third: There was no significant difference between the three groups. Overall, stepwise intraoperative activation was found to be more effective than conventional activation.
Rödig et al. 2010 [27]	EndoActivator Piezo Smart CanalBrush	NaviTip	Most of the samples showed clean root canal walls, with a high number of scores 1 and 2. No significant difference was detected among groups. Significantly more debris were removed from the coronal region than the apical except in the control group.
Klyn et al. 2010 [28]	EndoActivator 30K PEC Endosonic F-File	Max-i-Prob	No statistically significant difference in canal or isthmus cleanliness was found among the groups. However, all the intervention groups showed significantly cleaner canals and isthmuses at 3 and 5 mm in comparison with the sections at 1mm.
Malki et al. 2012 [29]	Suprasson PMax with the ultrasonic tip placed at 1, 2, 3, 4 and 5mm from the WL	NaviTip	The cleaning efficacy decreased with increasing the distance between the tip and the apex. Positioning the file at 1 and 2 mm from the apex exhibited significantly better debris removal than the other groups. Cleaning was observed up to 3 mm apically from the file tip.
Rödig et al. 2019 [30]	EndoActivator EDDY VDW Ultra	Endo-EZE	The percentage volume of debris produced during preparation significantly decreased after final irrigation in all groups. Overall, the mean percentage of debris reduction ranged between 44,1% and 66,8% with no significant differences among the four groups.
Deleu et al. 2013 [31]	Suprasson PMax Manual dynamic irrigation using gutta percha cone Er:YAG—2.940 nm with flat- fiber ended tip Er:YAG —2.940 nm (PIPS) with a conical fiber tip 980-nm diode laser	Monoject	SNI removed significantly less hard tissue debris than the intervention groups including the PUI group.
Thomas et al. 2014 [32]	Irrisafe EndoVac Modified EndoVac	Max-I-Prob	Statistically significant percentage reduction was found after the irrigation protocol in all groups. PUI performed significantly better than SNI group with a mean percentage reduction of 64,2% +/- 15,8 and 46% +/- 18.8 respectively.
Jiang et al. 2010 [33]	Suprasson PMax Newtron (with the oscillation perpendicular to the groove)	NaviTip	Significantly more hard tissue debris were removed in the activation groups compared to the SNI. Moreover, oscillation of the file toward the groove performed significantly better the oscillation of the file perpendicular to the groove with 95% and 50% of completely clean grooves respectively.
	Suprasson PMax Newtron (with the oscillation toward the groove)		

Table 8: Quality assessment and results. JBI, Joanna Briggs Institute.

Study	JBI 1	JBI 2	JBI 3	JBI 4	JBI 5	JBI 6	JBI 7	JBI 8	JBI 9	Total	Methodologic quality
Sabins et al. 2003 [17]	1	0	0	0	1	1	1	1	1	6	Moderate
Kanter et al./ 2011 [18]	0	0	1	0	1	1	1	1	1	6	Moderate
Linden et al./ 2020 [19]	0	0	1	0	0	1	1	1	1	5	Moderate
Urban et al./ 2017 [20]	0	0	1	0	1	1	1	1	1	6	Moderate
Duque et al./ 2016 [21]	1	0	1	0	1	1	1	1	1	7	High
Amato et al./ 2011 [22]	1	1	1	0	1	0	1	1	1	7	High
Haupt et al./ 2020 [23]	1	0	1	0	1	1	1	1	1	7	High
Castagnola et al. 2014 [24]	1	0	1	0	0	1	1	0	1	5	Moderate
Jiang et al. 2010 [25]	1	0	1	0	1	1	1	1	1	7	High
Plotino et al. 2020 [26]	1	0	1	0	0	1	1	1	1	6	Moderate
Rödig et al. 2010 [27]	1	0	1	0	1	1	1	1	1	7	High
Klyn et al. 2010 [28]	1	0	1	0	0	1	1	1	1	6	Moderate
Malki et al. 2012 [29]	1	1	1	1	1	1	1	1	1	9	High
Rödig et al. 2019 [30]	0	0	1	0	1	1	1	1	1	6	Moderate
Deleu et al. 2013 [31]	1	1	1	0	1	1	1	1	1	8	High
Thomas et al. 2014 [32]	1	0	1	0	1	1	1	1	1	7	High
Jiang et al. 2010 [33]	1	1	1	1	0	1	1	1	1	8	High

canals, four included straight root canals, six did not provide information about root canal curvature and one study included both straight and curved root canals [22]. All studies simulated the periapical area by closing the apex using mainly resin, only two articles used an open system [17,18]. The working length was standardized in seven studies by decoronating the teeth before instrumentation. Apical size and taper after root canals preparation ranged between 25 and 45 and 02 and 08 respectively. Moreover, five articles assessed the isthmus area in addition to the root canal either on horizontal sections under scanning electron microscope (SEM) and stereomicroscope or on scans using Micro-CT. The rest of the studies assessed the root canal walls only on longitudinal splits at magnification ranging between ×8 and ×1000. Grooves and depressions were created in six experiments and were filled with a mixture of dentine debris and NaOCl in order to simulate the accumulation of hard tissue debris in uninstrumented areas. Samples were reused repeatedly in the experimental groups in five studies.

Irrigation

Concentration of NaOCl used in the included articles ranged between 1 and 6,15% while EDTA was used at 17% except for one article where 15% EDTA was used [30]. Irrigation was performed through needles between 27 and 30 G and none of them exceeded 1mm from the working length. The largest volume of irrigant used was 12ml in 3 cycles of 30 seconds [20]. The total agitation time was varying. Three cycles of 20 seconds were the most reported agitation time (n=6).

Eleven studies evaluated both sonic and ultrasonic irrigation, five studies evaluated ultrasonic activation compared to conventional irrigation and one study reported about sonic agitation compared to conventional irrigation. The three sonic systems included in this review are described in Table 5. EndoActivator and EDDY systems were the most used at frequencies ranging between 160 and 190Hz for the EndoActivator and 6000Hz for EDDY system. Moreover, EDDY performed only once at 5000Hz [23]. Only polymer tips were used in sonic irrigation and none of the experiments inserted the tip deeper than 1 mm from the working length. Furthermore, the EDDY tips were used mounted on several sonic handpieces.

Several ultrasonic handpieces and stainless-steel tips were included in the review as described in Table 6. The IrriSafe tips were the most tested (n=6) and all the frequencies ranged around 30 KHz. The ultrasonic tips were inserted at 1mm from the working length as a maximal depth and 2mm as a minimal depth. However, Malki et al. [29] inserted the tips at 1, 2, 3, 4 and 5mm from the apex in order to evaluate the efficacy of the ultrasonic oscillation beyond the insertion depth. Only one article assessed the influence of the oscillation direction in the presence of a groove on the root canal wall [25]. Two included systematic reviews assessed different agitation techniques including sonic and ultrasonic irrigation in comparison with conventional irrigation [13,9], while Căpută reviewed ultrasonic irrigation only and assessed the removal of hard tissue debris as a secondary outcome [12].

Risk of bias within studies

A summary of the methodological quality assessment of the included controlled trials is presented in Table 8. None of the trials met all the criteria. After data extraction, the quality of the studies was assessed according to the JBI checklist as it was described previously. The included studies were classified as moderate methodologic quality and high methodologic quality.

The three included systematic reviews were classified as moderate methodologic quality [12,13] and high methodologic quality [9].

Summary measures

Three studies reported that passive ultrasonic activation was significantly more effective than sonic agitation in all the tested areas. Seven studies showed that there was no significant difference between the effectiveness of the two techniques. EndoActivator was found once to be significantly better than passive ultrasonic irrigation in hard tissue debris removal [18]. EDDY system was shown to be as effective as passive ultrasonic activation and both were significantly better than EndoActivator. Moreover, the three techniques were found to be more effective when used in stepwise intraoperative activation [26]. Five studies compared only passive ultrasonic activation to conventional irrigation and all of them showed significant effectiveness to ultrasonics. Furthermore, one of the last studies also reported that the cleaning efficacy could be observed up to 3mm apically from the file tip, however, debris removal decreases by increasing the distance between the file tip and the apex [29] (Table 7).

Three systematic reviews were included, Susila et al**.** included four articles assessing the efficacy of passive ultrasonic activation compared to conventional irrigation in debris removal and all of them showed significant better results for the passive ultrasonic irrigation groups [9]. Căpută et al. included twenty in vitro studies on debris removal using ultrasonics. Seventeen reported that passive ultrasonic irrigation removed significantly more hard tissue debris when compared to conventional irrigation, while two studies could not detect any significant difference between the two interventions [12].

Moreover, Virdee et al. assessed hard tissue debris removal in seven studies using several mechanical agitation techniques including passive ultrasonic activation and sonic agitation. All the experiments showed significant better results for intervention groups compared to conventional irrigation, but the lack of standardization between the studies did not allow the identification of the superior technique [13].

Discussion

The present review aimed to discuss the efficacy of passive ultrasonic activation compared to sonic agitation, and the efficacy of both techniques over conventional irrigation in terms of hard tissue debris removal during the root canal treatment. The component studies included either sonic or ultrasonic devices or both in addition to syringes and needles for the conventional method of endodontic irrigation.

A number of studies were excluded because of internal validity issues such as nonstandardized protocol of irrigation among the intervention groups which may affect the outcomes. External validity issues were also considered as reasons for exclusion such us the use of uncommon irrigation solutions and the presence of separated instruments within the root canals which may influence the debridment efficacy of the tested devices.

Overall, the findings confirm the superiority of both sonic and ultrasonic irrigation over the conventional method of irrigation in debris removal as it was shown in previous studies [34,35]. Moreover, most of studies showed no significant differences between sonic and ultrasonic devices. However, a moderate level of evidence indicated the superiority of passive ultrasonic irrigation over sonic irrigation.

In straight root canals the results were discrepant, this might be due to the wide variation in the irrigation time and the irrigant volumes used. In curved root canals no significant difference has been found between sonic and ultrasonic irrigation. During ultrasonic activation, acoustic streaming and cavitation of the irrigant are generated and produce shear stress along the root canal wall which allows the removal of hard tissue debris from the walls. The intensity of the acoustic streaming is widely related to the frequency which is about 30 KHz [36] and the displacement amplitude of the file into the canal that can reach a maximum of 135 µm [10]. In curved root canals, the file touches the canal walls and cannot oscillate freely which reduces the displacement amplitude and thus a reduction of the debridement efficacy occurs [10,36].

Also, cleaning in the coronal and middle portions of the root canal seems to be major compared to the apical portions independent of the agitation technique used. This could be related to the reduced diameter of the root canal lumen which may influence the volume of the irrigant, its flow and thus the efficiency of debris removal. In fact, several studies concluded a better cleaning efficiency with increasing the apical preparation size [37-39], however, one included study in the review prepared the canals to an apical size of 25 which can affect the cleaning [30]. Additionally, the formation of apical vapor lock due to the entrapment of gas in the apical region may hinder the irrigant penetration and affect the cleaning in the apical third. This occurs only in closed systems, however, two of the included studies [17,18] used open apex which does not simulate the clinical situation and may skew the results.

In a study by Plotino [26], stepwise intraoperative activation (SIA) of the irrigant was put to the test in comparison with conventional final activation of the irrigant. Devices used were ultrasonics, EndoActivator and EDDY and the three of them showed superiority while performing step by step during instrumentation phase each time the file was removed from the canal. In fact, SIA progressively removes the debris produced while shaping and prevent their packing into irregularities.

Three cycles of 20 seconds were the most reported agitation time in the included studies, however, Sabins [17] tested sonic and ultrasonic irrigation at both 30 and 60 seconds and found no significant differences between the two durations thereby concluding that final irrigation for as little as 30 seconds per canal could provide satisfying results.

Most of the included studies used scanning electron microscope to evaluate the amount of debris present on the canal walls. Nevertheless, this method only allows the analysis of some limited areas of the canal walls in addition to the bi-dimensional evaluation, thus, no thickness information of debris can be provided. On the other hand, two of the included studies used micro-CT for assessment of remaining debris [19,30]. This technology allows a precise three-dimensional observation of the root canal during the different steps of the treatment [40,41]. However, micro-CT scans require high radiations which contraindicate *in situ* assessment of accumulated hard tissue debris. One furthermore limitation is the fact that remaining soft tissue cannot be detected since micro-CT is based on radiographic images; only hard tissue debris can be viewed [3].

Evaluation of remaining debris used different scoring systems, from 3 to 5-grades, additionally magnification ranged between 8 and 1000×, therefore, results were varying due to methodological reasons. Furthermore, the different volumes and agitation times would explain the varying results too. Other than scoring systems, several studies calculated the percentage of remaining debris on the canal walls which gives more precise and objective results, even though outcome assessors were calibrated in the other studies before scoring.

Finally, assessment of remaining debris on the canal walls under microscopy requires sectioning of the roots which was performed in most of the included studies before the preparation. Nevertheless, some of the studies sectioned the roots right after the final irrigation protocols which may produce additional debris and thus affect the results.

Limitations

The results of the present review are based on *in vitro* studies only which represent a lower level of evidence compared to clinical trials. Moreover, the lack of standardization of the irrigation protocols including the volume of the irrigant and the time of agitation is a main factor of the variating results between the studies. Also, further studies should focus on the stepwise intraoperative activation of the irrigant in order to confirm its superiority.

Conclusion

Within the limitations of this systematic review, it can be concluded that sonic and ultrasonic activation of sodium hypochlorite is highly recommended as it increases the efficacy of hard tissue debris removal within the root canal. However, the current data could not find significant differences between the two activation techniques and subsequently none of them can be recommended over the other.

References

1. Haapasalo M, Endal U, Zandi H, et al. Eradication of endodontic infection by instrumentation and irrigation solutions. Endodontic Topics. 2005; 10: 77-102.
2. De-Deus G, Marins J, Silva E. J. N. L, et al. Accumulated Hard Tissue Debris Produced during Reciprocating and Rotary Nickel-Titanium Canal Preparation. Journal of Endodontics. 2015; 41: 676-681.
3. Paqué F, Laib A, Gautschi H, et al. Hard-Tissue Debris Accumulation Analysis by High- Resolution Computed Tomography Scans. Journal of Endodontics. 2009; 35: 1044-1047.
4. Gu L, Kim J. R, Ling J, et al. Review of Contemporary Irrigant Agitation Techniques and Devices. Journal of Endodontics. 2009; 35: 791-804.
5. Mohammadi Z. Sodium hypochlorite in endodontics: an update review. International Dental Journal. 2008; 58: 329-341.
6. Plotino G, Cortese T, Grande N. M, et al. New Technologies to Improve Root Canal Disinfection. Brazilian Dental Journal. 2016; 27: 3-8.
7. Gu L, Kim J.R, Ling J, et al. Review of Contemporary Irrigant Agitation Techniques and Devices. Journal of Endodontics. 2009; 35: 791–804.
8. Haapasalo M, Shen Y, Wang Z, et al. Irrigation in endodontics. British Dental Journal. 2014; 216: 299-303.
9. Susila A, Joseph Minu. Activated Irrigation vs. Conventional non-activated Irrigation in Endodontics – A Systematic Review. European Endodontic Journal. 2019; 4: 96-110.
10. Ahmad M, Pitt Ford T. R, Crum L. A, et al. Ultrasonic debridement of root canals: Acoustic cavitation and its relevance. Journal of Endodontics. 1988; 14: 486-493.
11. Rödig T, Koberg C, Baxter S, et al. Micro-CT evaluation of sonically and ultrasonically activated irrigation on the removal of hard-tissue debris from isthmus-containing mesial root canal systems of mandibular molars. International Endodontic Journal. 2019; 52: 1173-1181.
12. Căpută P. E, Retsas A, Kuijk L, et al. Ultrasonic Irrigant Activation during Root Canal Treatment: A Systematic Review. Journal of Endodontics. 2019; 45: 31-44.
13. Virdee S. S, Seymour D. W, Farnell D, et al. Efficacy of irrigant activation techniques in removing intracanal smear layer and debris from mature permanent teeth: a systematic review and meta-analysis. International Endodontic Journal. 2017; 51: 605-621.
14. Moher D, Liberati A, Tetzlaff J, et al. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Medicine. 2009; 6: e1000097.
15. Moher D, Schulz KF, Altman D. The CONSORT statement: Revised recommendations for improving the quality of reports of parallel-group randomized trials. JAMA. 2001; 285: 1987-1991.
16. Ethem Yaylali I, Kececi A. D, Ureyen Kaya B. Ultrasonically Activated Irrigation to Remove Calcium Hydroxide from Apical Third of Human Root Canal System: A Systematic Review of In Vitro Studies. Journal of Endodontics. 2015; 41: 1589-1599.
17. SABINS R, JOHNSON J, HELLSTEIN J. A Comparison of the Cleaning Efficacy of Short- Term Sonic and Ultrasonic Passive Irrigation after Hand Instrumentation in Molar Root Canals. Journal of Endodontics. 2003; 29: 674-678.
18. Kanter V, Weldon E, Nair U, et al. A quantitative and qualitative analysis of ultrasonic versus sonic endodontic systems on canal cleanliness and obturation. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology. 2011; 112: 809-813.
19. Linden D, Boone M, De Bruyne M, et al. Adjunctive Steps for the Removal of Hard-Tissue Debris from the Anatomical Complexities of the Mesial Root Canal System of Mandibular Molars: A Micro-CT Study. Journal of Endodontics. 2020; 46: 1508-1514.
20. Urban K, Donnermeyer D, Schäfer E, et al. Canal cleanliness using different irrigation activation systems: a SEM evaluation. Clinical Oral Investigations. 2017; 21: 2681-2687.
21. Duque J. A, Duarte M. A. H, Canali L. C. F, et al. Comparative Effectiveness of New Mechanical Irrigant Agitating Devices for Debris Removal from the Canal and Isthmus of Mesial Roots of andibular Molars. Journal of Endodontics. 2017; 43: 326-331.
22. Amato M, Vanoni-Heineken I, Hecker H, et al. Curved versus straight root canals: the benefit of activated irrigation techniques on dentin debris removal. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology. 2011; 111: 529-534.
23. Franziska Haupt, Michael Meinel, Asanka Gunawardana, et al. Effectiveness of different activated irrigation techniques on debris and smear layer removal from curved root canals: a SEM evaluation. Australian Endodontic Journal. 2019; 46: 40-46.
24. Castagnola R, Lajolo C, Minciacchi I, et al. Efficacy of three different irrigation techniques in the removal of smear layer and organic debris from root canal wall: a scanning electron microscope study. Giornale Italiano Di Endodonzia. 2014; 28: 79-86.
25. Jiang L-M, Verhaagen B, Versluis M, et al. Evaluation of a Sonic Device Designed to Activate Irrigant in the Root Canal. Journal of Endodontics. 2010; 36: 143-146.
26. Plotino G, Colangeli M, Özyürek T, et al. Evaluation of smear layer and debris removal by stepwise intraoperative activation (SIA) of sodium hypochlorite. Clinical Oral Investigations. 2020; 25: 237-245.
27. Rödig T, Döllmann S, Konietschke F, et al. Effectiveness of Different Irrigant Agitation Techniques on Debris and Smear Layer Removal in Curved Root Canals: A Scanning Electron Microscopy Study. Journal of Endodontics. 2010; 36: 1983-1987.

28. Klyn S. L, Kirkpatrick T. C, Rutledge R. E. In Vitro Comparisons of Debris Removal of the EndoActivatorTM System, the F FileTM, Ultrasonic Irrigation, and NaOCl Irrigation Alone after Hand-rotary Instrumentation in Human Mandibular Molars. Journal of Endodontics. 2010; 36: 1367-1371.
29. Malki M, Verhaagen B, Jiang L-M, et al. Irrigant Flow beyond the Insertion Depth of an Ultrasonically Oscillating File in Straight and Curved Root Canals: Visualization and Cleaning Efficacy. Journal of Endodontics. 2012; 38: 657-661.
30. Rödig T, Koberg C, Baxter S, et al. Micro-CT evaluation of sonically and ultrasonically activated irrigation on the removal of hard-tissue debris from isthmus-containing mesial root canal systems of mandibular molars. International Endodontic Journal. 2019; 52: 1173-1181.
31. Deleu E, Meire M. A, De Moor R. J. G. Efficacy of laser-based irrigant activation methods in removing debris from simulated root canal irregularities. Lasers in Medical Science. 2013; 30: 831-835.
32. Thomas A. R, Velmurugan N, Smita S, et al. Comparative Evaluation of Canal Isthmus Debridement Efficacy of Modified EndoVac Technique with Different Irrigation Systems. Journal of Endodontics. 2014; 40: 1676-1680.
33. Jiang L-M, Verhaagen B, Versluis M, et al. Influence of the Oscillation Direction of an Ultrasonic File on the Cleaning Efficacy of Passive Ultrasonic Irrigation. Journal of Endodontics. 2010; 36: 1372-1376.
34. Paragliola R, Franco V, Fabiani C, et al. Final Rinse Optimization: Influence of Different Agitation Protocols. Journal of Endodontics. 2010; 36: 282-285.
35. Lee S-J, Wu M-K, Wesselink P. R. The effectiveness of syringe irrigation and ultrasonics to remove debris from simulated irregularities within prepared root canal walls. International Endodontic Journal. 2004; 37: 672-678.
36. Van der Sluis L. W. M, Versluis M, Wu M. K, et al. Passive ultrasonic irrigation of the root canal: a review of the literature. International Endodontic Journal. 2007; 40: 415- 426.
37. Rollison S, Barnett F, Stevens R. H. Efficacy of bacterial removal from instrumented root canals in vitro related to instrumentation technique and size. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology. 2002; 94: 366-371.
38. Fornari V. J, Silva-Sousa Y. T. C, Vanni J. R, et al. Histological evaluation of the effectiveness of increased apical enlargement for cleaning the apical third of curved canals. International Endodontic Journal. 2010; 43: 988-994.
39. Rodrigues R. C. V, Zandi H, Kristoffersen A. K, et al. Influence of the Apical Preparation Size and the Irrigant Type on Bacterial Reduction in Root Canal–treated Teeth with Apical Periodontitis. Journal of Endodontics. 2017; 43: 1058-1063.
40. De-Deus G, Marins J, de Almeida Neves A, et al. Assessing Accumulated Hard-tissue Debris Using Micro–computed Tomography and Free Software for Image Processing and Analysis. Journal of Endodontics. 2014; 40: 271-276.
41. Keleş A, Alçin H, Sousa-Neto M. D, et al. Supplementary Steps for Removing Hard Tissue Debris from Isthmus-containing Canal Systems. Journal of Endodontics. 2016; 42: 1677-1682.