

## Assessment of the Effectiveness of Supplementary Methods for Residual Filling Material Removal Using Micro-computed Tomography: A Systematic Review and Meta-analysis of *In Vitro* Studies

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### ABSTRACT

A systematic review and meta-analysis were conducted to evaluate the effectiveness of auxiliary methods in removing residual filling material (RFM). This systematic review has been registered with the International Prospective Register of Systematic Reviews (registration number CRD42020197482). A comprehensive literature search was conducted to identify relevant articles in electronic databases (PubMed, Embase, Cochrane) from January 2005 to March 2021. *In vitro* studies investigating or comparing at least one type of supplementary method or technique were included. A total of 26 studies were selected from the 239 records obtained after screening the databases. Ten of the included studies were suitable for meta-analysis. Strong evidence showed that ultrasonically activated irrigation (UAI) [SMD (95% CI): -0.52 (-0.88 to -0.16, P=0.266)] and XP-Endo Finisher R (XPR) [SMD (95% CI): -0.55 (-0.89 to -0.20, P=0.136)] contributed significantly to increase the removal procedure, and XPR has no significant superiority over UAI [SMD (95% CI): 0.36 (-0.12 to 0.84, P=0.994)]. Strong evidence was found to support the increased cleaning efficiency of the supplementary use of the Gentle Wave system, laser irradiation, XP Endo Finisher, and self-adjusting file. In contrast, conflicting evidence was found to support the use of sonic to improve the removal of RFM, and limited evidence was found to support the efficiency of Tornado Brush. Under *in vitro* conditions, UAI and XPR increase the removal of RFM from the root canal system during retreatment procedures.

**Keywords:** Auxiliary methods, micro-computed tomography, residual filling material, retreatment, root canal

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### HIGHLIGHTS

- Both UAI and the XPR increase the removal of RFM from the root canal system during retreatment procedures.
- Supplementary use of GW, LI, XPEF, and SAF increased the cleaning efficiency of retreatment procedures.
- The use of sonic to improve the removal of RFM need more support.

### INTRODUCTION

Retreatment is defined as "a procedure to remove the root canal filling material from the tooth, followed by cleaning, shaping and obturating the canals" by the AAE Glossary of Endodontic Terms (1). Ideally, during the process of root canal retreatment, all existing filling material should be removed (2). The remaining root canal filling material (RFM) will lead to the re-infiltration of residual microorgan-

isms and their toxins between the sealant and the root canal wall, leading to periapical tissue inflammation and affecting the long-term effect of root canal retreatment (3-6). Therefore, the evaluation of the clearance efficiency of root canal fillings can indirectly predict the effect of root canal retreatment.

Traditionally, both destructive and radiographic methods are used for the evaluation of RFM, such as tooth splitting and microscopic assessment of the structures, two-dimensional periapical radiography, cone-beam computed tomography, and micro-computed tomography (micro-CT) imaging (7-10), among which micro-CT is considered a research method with the advantage of high-resolution (11).

In 2017, a systematic review discussed the effectiveness of different instrumentation procedures in removing root-canal filling materials and concluded that the instrumentation protocols can-

not completely remove RFM from the root canal system (12). Micro-CT studies have shown that the mean percentage of RFM ranges from 43.9% to 0.02%, with most studies reporting values less than 10% (13, 14). Nonetheless, 0.5% RFM has been suggested as a cutoff point to reflect "effective canal cleaning" (15). Numerous studies have shown that even when using nickel-titanium rotary or reciprocating instruments with various designs and alloys, the complete removal of root canal filling material is almost impossible (13, 16-20). Therefore, supplementary techniques to enhance filling material removal and canal cleaning have been proposed as an adjunct to mechanical retreatment (21-24).

Numerous studies have investigated supplementary methods for removing RFM from the root canal system after instrument preparation. In addition, some studies have evaluated the potential of irrigation methods, such as ultrasonically activated irrigation (UAI) (19, 21-23, 25-30), sonically activated irrigation (SAI) (31), apical negative pressure (ANP) irrigation using the EndoVac system (Discus Dental, Culver City, America), and a side-vented needle (ProRinse; Dentsply Sirona, York, America) (32), and laser-activated irrigation (LAI) (27, 33, 34). The effectiveness of different supplementary files along with an irrigation solution (15, 23, 24, 29, 35-41) and endodontic brushes (15) has also been assessed in past studies. Despite abundant literature reporting on the efficacy of these techniques, outcomes are often conflicting. This indicates the need for a systematic review of the literature to elucidate the effectiveness of supplementary cleaning methods. Therefore, this systematic review aimed to evaluate the effectiveness of supplementary methods in removing RFM in addition to instrumental preparation during root canal retreatment.

## MATERIALS AND METHODS

### Protocol and registration

The study protocol was registered in the PROSPERO international prospective database of systematic reviews under the registration number CRD42020197482. This systematic review was prepared following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-analysis statement (<http://www.prisma-statement.org>).

### Literature search strategy

An electronic search was conducted in the PubMed, Embase, and Cochrane library databases (January 2005-March 2021). "Do supplementary steps after a reciprocating single- or rotary multi-instrument system preparation during the process of root canal retreatment improve the removal of the RFM?" was the interest of this review.

### PICOS question

The population, intervention, comparison, and outcome (PICO) strategy used for the structured review question were based on the PICOS strategy (PRISMA-P 2016) as follows:

Population (P): Extracted mature human teeth;

- Intervention (I): Removal of root canal filling material using either a reciprocating single- or rotary multi-instrument system with a supplementary step;

- Comparison (C): Removal of root canal filling material using either a reciprocating single- or rotary multi-instrument system without a supplementary step;
- Outcome (O): Assessment of the volume of the RFM in the root canal after a supplementary step;
- Study (S): *In vitro* comparative study.

The main search terms were "micro-CT", "root canal filling", "RFM", and "removal". The language was restricted to English. An example of the final search strategy is presented in Table 1. Moreover, three main endodontic journals, the Journal of Endodontics, International Endodontic Journal, and Australian Endodontic Journal, were manually searched for articles that were not found in the databases but were in the press. After removing duplicate articles, the references of the selected papers were further searched to obtain pertinent articles.

### Eligibility criteria

#### Inclusion criteria were as follows:

1. *In vitro* studies performed root canal retreatment procedures on mature permanent human teeth.
2. Studies comparing the amount of RFM before and after using supplementary methods.
3. Micro-CT was used to evaluate the amount of RFM.

#### Exclusion Criteria were as follows:

1. Studies performed on artificial teeth or animal teeth.
2. Studies without micro-CT data of the RFM after the first removal.
3. Reviews, letters, opinion articles, and conference abstracts.

### Study selection process

Two trained reviewers (X.Y. and J.L.) independently screened the titles and abstracts, followed by the full texts to select studies according to the inclusion criteria mentioned above and exclusion criteria. Any disagreements between the two reviewers were resolved by discussion with a third experienced reviewer (C.T.).

### Data extraction and synthesis of evidence

Two reviewers (X.Y. and J.L.) worked independently to extract data from the included articles. Any reviewer disagreements were resolved by discussion with a third reviewer (C.T.). The data extracted included specific details about the authors, populations, interventions, study methods, and main findings. In addition, data extraction was performed to assess the impact of supplementary methods on removing RFM. Finally, a meta-analysis was limited to those where outcomes were quantitatively presented as means and standard deviations.

### Quality Assessment (Risk of Bias)

The revised Cochrane risk-of-bias tool (RoB 2.0) for randomised trials was used to evaluate the risk of bias arising from the following domains: sample size calculation, randomisation process, standardisation of the anatomical morphology of

**TABLE 1.** Example of the search strategy (PubMed)

No	Search strategy	Results
1	("Microcomputed tomography") OR ("Micro-computed tomography") OR (Micro CT) OR (Micro-CT)	21578
2	(endodontic*) OR ("root canal") OR ("dental pulp cavity") OR ("teeth") OR ("tooth")	256903
3	("removal") OR ("remnant") OR ("remaining") OR (cleanliness) OR "retreatment" OR "retrieval"	763855
4	("gutta-percha") OR ("gutta percha") OR (sealer) OR (paste) OR ("sealant") OR ("filling") OR (obturation)	200255
5	#1 AND #2 AND #3 AND #4	123

CT: Computed tomography

teeth, blinding of the outcome evaluator, measurement of the outcome and selection of the reported result.

To make a general judgment of the risk of individual bias, each included study was judged as having a 'low', 'moderate', and 'high' risk of bias in the case of a positive domain response (green), a 'high' risk of bias in the case of a negative domain response (red), and an 'uncertain' risk of bias (yellow) when the response was not clear (42). And studies were initially judged

as 'uncertain', leading to contacting the authors for more information allowing us to finally classify their study as 'low', 'moderate', or 'high' risk of bias.

### Meta analysis

The results of the eligible studies were analyzed using a software program for meta-analysis (Stata 12.1). The change in the volume of RFM with the use of supplementary methods was selected as the outcome. The sample size of each group and the mean and standard deviation related to the volume of RFM before and after using supplementary methods were extracted from the studies. Standardised mean difference (SMD) was calculated for each included study. Results were presented in forest plots. Statistical heterogeneity between studies was evaluated by the I<sup>2</sup> value (43). Due to the I<sup>2</sup> score being towards 50%, the fixed-effects model was used.

## RESULTS

### Literature search and study selection

The literature search resulted in a total of 239 articles from PubMed, Embase, and Cochrane Library and 81 articles from the manual search. Following duplicate removal, 123 studies remained. The initial selection was conducted by screening

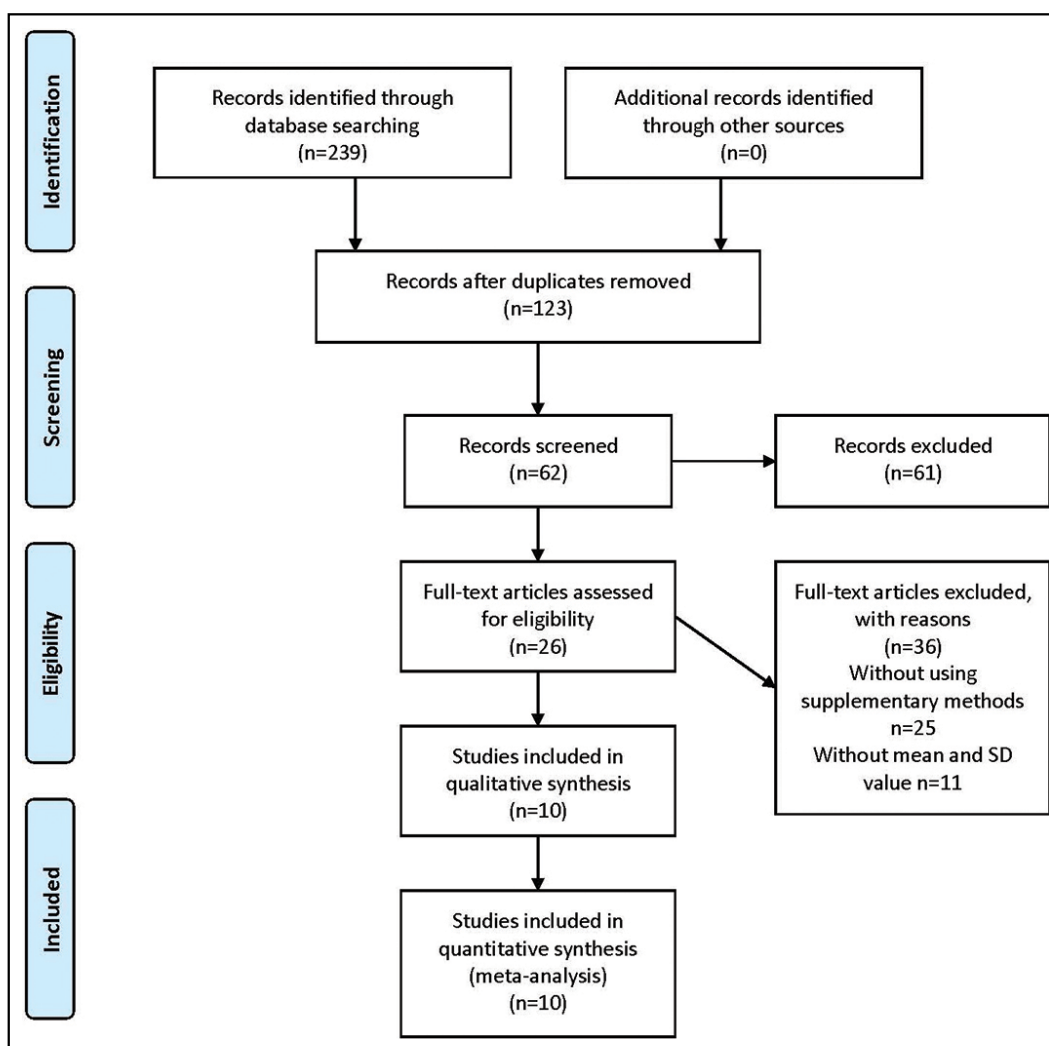


Figure 1. A flow chart of the literature search and the selection process according to the PRISMA statement

titles and abstracts, and 61 studies were deemed beyond the scope of the reviewers. The corresponding full text was read when the eligibility of a given article was unclear. Twenty-six studies satisfied the inclusion criteria. The details and results of the search strategy were shown in Figure 1.

### Characteristics of the included studies

Table 2 summarises the characteristics of the reviewed studies. Included studies evaluated the efficiency of UAI, XP-Endo Finisher R (XPR), LAI, Gentle Wave system (GW), or SAI and mechanical instruments, XP-Endo Finisher (XPEF), XPR, self-adjusting file (SAF), and Tornado Brush (TB) compared with that of different supplementary techniques. Finally, 26 studies were found suitable for the present systematic review.

Among the studies, the apical reparation diameter varied among the experimental groups and consisted of 0.20 mm (25, 27, 32, 44), 0.25 mm (20, 26, 27), 0.30 mm (38, 39, 45), 0.35 mm (37, 41), 0.40 mm (17, 19, 22, 24, 29-31, 35, 46), 0.45 mm (33), and 0.50 mm (21, 23, 28, 34, 40). Different filling materials were applied during the first therapy and included the epoxy resin-based sealer AH Plus (Dentsply De Trey, Konstanz, Germany) (17, 20, 23, 25, 26, 29, 31-36, 39-41, 44, 46, 47), a bioceramic sealer (19, 22, 23, 38, 45), and Endofill sealer (Dentsply Maillefer, Ballaigues, Switzerland) (26, 30). Additionally, some studies used the continuous-wave vertical compaction technique (WVC) (17, 26-28, 31-33, 36, 41, 46), some used the single-cone technique (SC) (19, 20, 22-25, 29, 30, 35, 37, 38, 44, 45), and others used cold lateral compaction (CLC) (34, 36, 39, 40). On the other hand, concerning the supplementary techniques, various methods were used to improve the cleaning of the root canal, including UAI (19, 21, 25, 26), LAI, and supplementary files (17, 24, 36-40, 47). Comparisons of the efficiency of several different supplementary methods were also made (22, 23, 27-30, 32, 35, 40, 45).

### Data collection

The data collected from the 26 included studies were summarised in Table 2.

### Risk of Bias

The risk of bias assessment for all the included studies is shown in Figure 2. In total, 15 studies were considered 'low' risk, while 11 studies had moderate methodological scores. Strong evidence was found to support the increased cleaning efficiency of the supplementary use of UAI, GW, LI, XPEF, XPR, and SAF. In contrast, conflicting evidence was found to support the use of sonic to improve the removal of RFM, and limited evidence was found to support the efficiency of TB. In addition, conflicting evidence was found for the efficiency of UAI compared to XPR.

### Meta-analysis

Ten of the included studies were suitable for meta-analysis. Based on the analyses, UAI contributed significantly to increasing the removal procedure [SMD (95% CI): -0.52 (-0.88 to -0.16,  $P=0.266$ )] (Fig. 3), XPR significantly improved the removal of RFM [SMD (95% CI): -0.55 (-0.89 to -0.20,  $P=0.136$ )] (Fig. 3). An additional analysis was performed to compare the efficiency of XPR and UAI. XPR had no significant superiority in the RFM removal compared to UAI [SMD (95% CI): 0.36 (-0.12 to 0.84,  $P=0.994$ )] (Fig. 4).

### XPEF

Two studies evaluated the XPEF (FKG Dentaire, La Chaux-de-Fonds, Switzerland). Alves et al. (24) found that the XPEF significantly improved RFM removal by 69% after using a rotary multiple-instrument system and reciprocating single-instrument system. Furthermore, Aksel et al. (38) reported that additional preparation with the XPEF improved the removal of RFM regardless of the sealer type. Therefore, this review found convincing evidence of the efficiency of the XPEF in enhancing the removal of RFM.

### GW

Two studies were found comparing the GW with other irrigation methods (28, 32). Wright et al. (32) reported that although the efficiency of the GW (Sonendo, Inc., Laguna Hills, CA, USA) was similar to that of the side-vented needle, the results were better than those of the EndoVac system. However, Crozeta et al. (28) found that compared to the GW, passive ultrasonic irrigation had superior results. Therefore, there is limited evidence for the effectiveness of the GW.

### LI

Two studies found that the additional application of a laser improves the removal of RFM in oval-shaped canals (33, 34). Keleş et al. (33) found that an Er:YAG laser (2,940 nm, Fidelis AT; Fotona, Ljubljana, Slovenia) was more efficient than Er:YAG-based photon-induced photoacoustic streaming (PIPS) and an Nd:YAG laser (1064 nm, Fotona, Ljubljana, Slovenia). Jiang et al. (27) examined the activation of NaOCl with Er:YAG-based PIPS (Fidelis AT, Fotona, Ljubljana, Slovenia) and found that it showed significantly better performance than sonic and ultrasonic techniques in removing RFM following the mechanical retreatment of oval root canals. However, Dönmez Özkan et al. (34) discovered that compared to conventional needle irrigation, the PIPS method did not add a significant effect in removing filling material. The largest sample size included 15 teeth. Due to the differences among studies, such as nonstandard instrumentation, different irritants, and different types of teeth, the overall performance of the irrigation methods may be affected even if the comparisons within each study remained valid. Therefore, there was conflicting evidence in the results, and not enough evidence was found for the efficiency of LI in aiding filling removal.

### SAF

Three studies evaluated the efficiency of the SAF (ReDent-Nova, Ra'anana, Israel) (36, 39, 41). Keleş et al. (36) and Simsek et al. (39) reported that the additional use of the SAF enhanced the removal of RFM after the retreatment procedure in straight and curved root canals using rotary systems. Silva et al. (41) found that both the SAF (ReDent Nova, Ra'anana, Israel) and the Hedström File (Dentsply Maillefer, Ballaigues, Switzerland) could improve RFM removal from C-shaped canals, but the Hedström file significantly reduced the remaining filling material compared to the SAF in the total canal length (30% vs 18%). The largest sample size included 20 teeth. This review found moderate evidence of the efficiency of the SAF in removing RFM.

### SAI

Two studies (30, 31) were related to SAI. Kaloustian et al. (31) reported that compared to using instrumental preparations

**TABLE 2.** A summary of the methodology and the results of the studies evaluating the percentage of residual material reduction

Study	Root morphology and sample size	Retreatment instruments (Step1, Step2); filling methods; and apical diameter of preparation (mm)	Supplementary strategy; Type of file/tip; Irrigants	Percentage of residual material reduction and main findings
Silveira et al. (2018)(19)	Mesial roots of mandibular molars (N=40c; n=20c)	(Mani GPR/HyFlex NT, UAI); GP and sealer 26 with SC; 0.40	UAI; NM; 2.5% NaClO+17% EDTA	PUI and UAI significantly reduced the amount of filling remnants.
Da Rosa et al. (2015)(25)	Mesiobuccal and distobuccal root canals of maxillary Molars (N=20t)	(PTUR, ProTaper F2 or wave one, UAI); GP and AH with the SC; 0.20	UAI; Ultrasonic tip (15/0.02); 1% NaClO	UAI did not improve the removal of root canal filling material.
Bernardes et al. (2016)(21)	Mandibular incisors (N=108t; n=18t)	(Reciproc/PTUR/ Hand files or Gates-Glidden, no UAI/UAI); GP and AH;0.50	UAI; Jet Sonic and Irrisonic tip (20/0.01); 2.5% NaClO+17% EDTA	UAI improved the removal of root filling material in all groups.
Kaloustian et al. (2019)(26)	Mesial roots of mandibular molars (N=88c; n=22c)	(TS2+Endo Ultra/TS2+Irrisafe/Reciproc+Endo Ultra/Reciproc + Irrisafe); GP and EWT with WVC; 0.25	UAI; File (20/0.02); 6% NaClO+17% EDTA	The UAI significantly enhanced the removal of the filling material.
Pedullà et al. (2019)(22)	Single-rooted mandibular premolars (N=72t, n=12t)	(R-Endo R3+Hyflex EDM40 #04BioRootRCS/ GuttaFlow Bioseal+SNi/TB/UAI); GP and G1, G2 with the SC; 0.40	SNI, TB, UAI; Ultrasonic file (Irrisafe 25); 3% NaClO+17% EDTA+Sterile saline	UAI and TB were more effective than syringe irrigation in removing BR.
Barreto et al. (2016)(44)	Mesial roots of mandibular molars (N=30r, n=5r)	(ProTaper Retreatment instruments, Conventional/UAI or NaClO/UAI or orange oil); Repaired with X2 and X3 ProTaper Next instruments; GP and AH with the SC; 0.20	UAI/NaClO, UAI/orange oil; Ultrasonic tip; 2.5% NaClO	UAI with NaClO or orange oil did not improve filling material removal.
Alves et al. (2016)(24)	Teeth with mesial root curvatures (N=40c, n=20c)	(Mtw /Reciproc, XPEF); GP and sealer 26 with the SC;0.40	XPEF; 2.5% NaClO	69%, XPEF significantly enhanced the removal of filling material.
Campello et al. (2019)(37)	Mandibular molars (N=32c, n=16c)	(Mtw retreatment instruments with or without Eucalyptol, XPR); GP and sealer 26 with the SC; 0.35	XPR; (2.5% NaClO+17% EDTA)/(G1+ Eucalyptol)	42%, XPR significantly improved removal of filling material.
Machado et al. (2019)(47)	Mandibular molars (N=60 c, n=20c)	(D-RaCe system, SAF/TRUShape/XP-endo Shaper, XPR); Mtw gutta-percha cone with WVC; 0.30	XPR; 2.5% NaClO+17% EDTA+ distilled water	38%XPR instrument enhanced filling material removal.
Aksel et al. (2019)(38)	Mesiobuccal root canals of mandibular 1 <sup>st</sup> molars (N=30c, n=10c)	(PTUR, XPEF); GP with the SC, AH Plus, NeoMTA Plus or Endosequence BC; 0.30	XPEF; 2.5% NaClO	XPEF improved the removal of filling material.
Volponi et al. (2020)(45)	Mandibular premolar teeth (N=36t, n=12t)	(PTN+UAI/EAI/XPEF); GP and Bio-C Sealer with SC; 0.30	UAI, EAI, XPR; 17% EDTA	XPR led to significantly greater filling material removal than UAI or EAI.
De-Deus et al. (2019) (11)	Mandibular incisors (N=30t, n=10t)	(M-Wire Reciproc R25, M-Wir, Reciproc R25/ Reciproc Blue R25/XP-endo Shaper); GP and AH ; 0.40	Conventional needle; 2.5% NaClO+17% EDTA	The increase in apical enlargement improved the removal of root fillings.
Tavares et al. (2020)(40)	Mandibular 1 <sup>st</sup> premolars (N=24t, n=12t)	(Reciproc R50, XPR/R1-Clearsonic insert); GP and Sealer 26 with CLC; 0.50	XPR, R1-Clearsonic insert; 2.5% NaClO	XPR and R1-Clearsonic;47.9% and 52.2% in the apical segment and 82.1% and 64.6% in the full canal.
Silva et al. (2018) (17)	Maxillary single-rooted teeth (N=20t, n=10t)	(Reciproc R25 and R40, XPEF and XPR); GP and AH with the continuous wave of condensation; 0.40	XPEF, XPR; 2.5% NaClO	Both XPEF and XPR were equally effective in the removal of remaining filling material.
Simsek et al. (2014) (39)	Mandibular 1 <sup>st</sup> molars (N=40c, n=10c)	(D-RaCe, SAF); SAF+GP and AH with CLC or with TT Revo-5+GP and AH with CLC or with TT; 0.30	SAF; 2.5% NaClO+17% EDTA	Additional use of SAF enhanced the removal of filling material.
Keleş et al. (2014) (36)	Maxillary premolars (N=20c, n=10c)	(R-Endo retreatment rotary instruments, SAF); GP and AH with CLC or VC; 0.25	SAF; 15% EDTA+5% NaClO	Additional use of SAF significantly improved the removal of filling material with R-Endo instruments.

**TABLE 2.** Cont.

Study	Root morphology and sample size	Retreatment instruments (Step1, Step2); filling methods; and apical diameter of	Supplementary strategy: Type of file/tip; Irrigants	Percentage of residual material reduction and main findings
Silva et al. (2020) (41)	Mandibular 2 <sup>nd</sup> molars (N=20t, n=10t)	(Reciproc system R25 and Mtwo rotary system, SAF/H file); GP and sealer 26 with WVC; 0.35	SAF or H file; 1% NaClO;	The SAF file was less effective than the H file in removing the RFM.
Martins et al. (2017)(30)	Mandibular premolar (N=32c, n=8c)	Reciproc 40 +Irrisonic Tip (PUI)/RS: Reciproc 40+EndoActivator /ProTaper Next with Irrisonic Tip/ProTaper Next with EndoActivator; GP and Endofill with SC;0.40	PUI or Sonic agitation; 2.5% NaOCl	The additional cleaning methods did not improve the removal of filling material significantly.
Wright et al. (2019) (32)	Mesial canals of mandibular 1 <sup>st</sup> and 2 <sup>nd</sup> molars (N=30t, 60c; n=10 t, 20c)	(The elementsfree downpack and a .06 tapered heated plugger, .04 taper Profile rotary files, a 30-G side-vented needle/ EndoVac/ GentleWave); GP and resin sealer; 0.20	A 30-G side-vented needle, EndoVac, GentleWave; 5.25% NaOCl+17% EDTA, 3% NaOCl+8% EDTA	Both the side-vented needle and GentleWave groups were able to remove on average more residual obturation material than the EndoVac group. however, the differences were not significant.
Kaloustian et al. (2019)(31)	Mandibular molars (N=40t, n=20t)	(2Shape system/Reciproc system, MM1500 or Eddy device); X2 GP point and AH Plus sealer; 0.40	MM1500 or Eddy device; a 30 G Navitip needle; 6% NaOCl+17% EDTA	Sonic activation with MM1500 and Eddy significantly improved filling material removal.
Crozeta et al. (2021)(23)	Distal roots of mandibular molars (N=28c, n=14c)	(R50, Ultrasonic tips/XPR); GP and AH or BC with the SC; 0.50	Ultrasonic tips or XPR, R2 Flatsonic ultrasonic (size 30), Navitip 30-G needle; 2.5% NaOCl	Ultrasonic tips should be considered a good option for endodontic retreatment, especially for bioceramic cases.
Borges et al. (2019) (29)	Mandibular incisors (N=36t, n=12t)	(Solvent, RB/PDR/WOG, XP-Endo Shaper/PUI/H file); GP and AH Plus; 0.40/0.35/0.35	XP-Endo Shaper, PUI, #30 H file; a 30-gauge needle; 1% NaOCl/ (17% EDTA+2.5% NaOCl)	The XP-endo Shaper promoted significantly fewer remaining filling materials in the middle and apical thirds.
Crozeta et al. (2020)(28)	Distal roots of mandibular Molars (N=20t, n=10t)	(A Reciproc 50.05 instrument (VDW), UAI/ GentleWave); Gutta-percha and AHPlus sealer using warm-vertical obturation; 0.50	UAI/GentleWave; E1-Irrisonic (20/0.01); (3% NaClO+17% EDTA)/ (3% NaOCl+water rinse+8% EDTA)	UAI showed better performance than GentleWave.
Jiang et al. (2016)(27)	Single-rooted Maxillary 1 <sup>st</sup> premolars (N=28t, n=7t)	(Gates Glidden burs, ProTaper universal retreatment system (D1-D3), No further/ PIPS/Sonic (EndoActivator)/Ultrasonic); gutta-percha and AH Plus; 0.30	PIPS/Sonic/Ultrasonic Sonic, UAI, Er:YAG laser; Sonic tip (0.2/0.02), Ultrasonic tip (0.2, 0.02); 3% NaOCl+17% EDTA	The additional use of PIPS for the activation of NaClO was superior to sonic and ultrasonic techniques in removing the remaining filling materials
Keleş et al. (2015)(33)	Single-rooted Mandibular canines (N=42t, n=14t)	(R-Endo NiTi + 45# K-file, Er: YAG laser with optic fiber plain tip/Er:YAG lase with a tapered PIPS fiber tip/ Nd: YAG laser with a fiber plain tip); GP and AH plus with VC; 0.45	Er: YAG laser/Er: YAG laser PIPS/Nd: YAG laser; 5% NaClO+17% EDTA	The additional use of lasers improved the removal of filling material.
Dönmez Özkan et al. (2019)(34)	Single-rooted Mandibular premolars (N=60t, n=15t)	PTR and conventional needle/PTR and needle with PIPS activation/HyFlex EDM/HyFlex EDM with PIPS activation; 35# gutta-percha and AH Plus sealer; 0.50	Conventional needle/needle+PIPS; 17% EDTA+5% NaClO	PIPS method did not show a significant additional effect regarding the removal of filling material.

UAI: Ultrasonically activated agitation, GP: Gutta-percha, SC: The single-cone technique, NM: Not mentioned, EDTA: Ethylenediaminetetraacetic acid, TB: Tornado Brush, XPEF: XP-Endo Finisher, PTR: ProTaper Universal Retreatment, XPR: XP-endo Finisher R, SAF: Self-adjusting file, EAI: EndoActivator Irrigation, PIPS: Photon-induced photoacoustic streaming, EDM: Electrical discharge machining, AH: AH Plus sealer, WVC: Continuous-wave vertical compaction technique, CLC: Cold lateral compaction, TT: Thermoplasticized injectable techniques, VC: Vertical condensation, H file: Hedström file, t: Teeth, c: Canal, r: Root, s: Syringe irrigation, EAI: EndoActivator irrigation, RB: Reciproc Blue, PDR: ProDesign R, WOG: WaveOne Gold, PUI: Passive ultrasonic irrigation

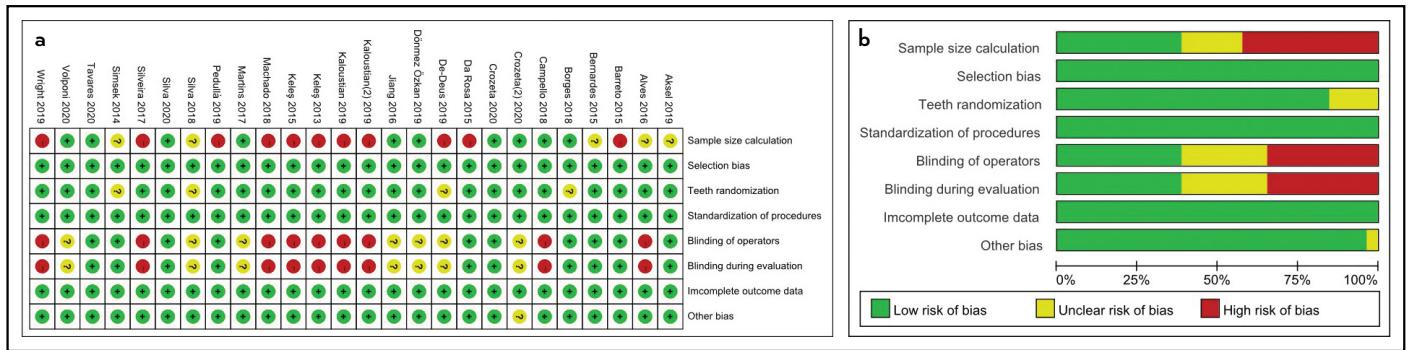


Figure 2. Risk of bias results of the included studies. (a) Risk of bias summary, (b) Risk of bias graph

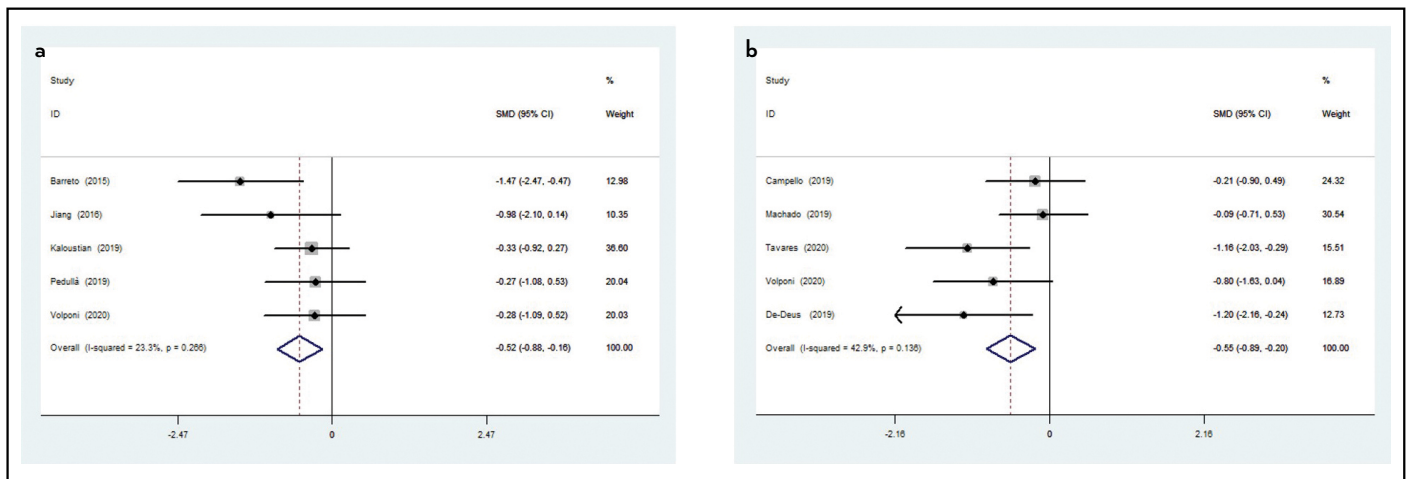


Figure 3. Forest plots of meta-analyses. (a) UAI, (b) XP-Endo finisher R  
UAI: Ultrasonically activated irrigation, SMD: Standardised mean difference, CI: Confidence interval

alone, using two sonic irrigation devices, Eddy (VDW) and MM1500 (Micro-Mega) after instrumental preparation could significantly improve the filling material removal. However, Martins et al. (30) found the SAI (EndoActivator) (Dentsply Tulsa Dental Specialties, Tulsa, OK, America) was similar to UAI (Irrisonic Tip; Helse, Santa Rosa do Viterbo, SP, Brazil) but did not improve the removal of RFM significantly. Therefore, there was conflicting evidence in the results.

**TB**

TB (Tornado France, M.I. B, Suresnes, France) can remove the RFM by generating the hydrodynamic shear stresses from the ultrasonic tips and centrifugal forces to brush the root canal walls (48). Pedullà et al. (22) reported that while the TB, syringe irrigation, and UAI achieved the same level of residual GuttaFlow Bioseal removal (GuttaFlow Bioseal, Coltene/Whaledent AG, Langenau, Germany) in the root canal, ultrasonic activation and the TB were more effective than syringe irrigation in removing BioRoot RCS (BioRoot RCS, Septodont, Saint Maur-des-Fosses, France). Since there is only one report on the use of TB in the removal of RFM, there is limited evidence for the efficiency of TB in removing RFM.

**DISCUSSION**

It is important to understand the efficiency of supplementary strategies that may potentially help improve the long-term success of endodontic retreatment. Based on the findings of this systematic review, the supplementary use of XPR and UAI

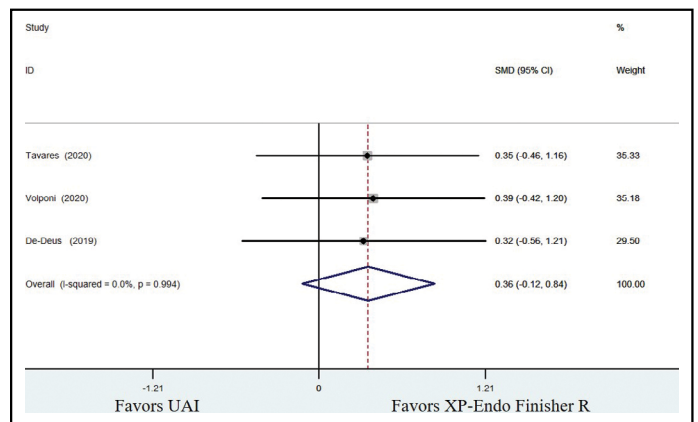


Figure 4. Forest plots of meta-analyses  
UAI: Ultrasonically activated irrigation, SMD: Standardised mean difference, CI: Confidence interval

significantly increases the removal of RFM during retreatment procedures, and XPR has no significant superiority over UAI. In addition, strong evidence was found to support the increased cleaning efficiency of the supplementary use of GW, LI, XPEF, and SAF, while conflicting evidence was found to support the use of sonic to improve the removal of RFM, and limited evidence was found to support the efficiency of TB.

The present review focused on the studies which assess the effectiveness of supplementary techniques for RFM

removal using micro-CT. The results of the meta-analysis demonstrated the efficiency of XPR and UAI in removing RFM during the retreatment procedure. This finding is in contrast to Uzunoglu-Özyürek (49). However, this may relate to anatomical differences, the type of root canal sealer, and initial retreatment procedures. Therefore, further standardisation studies are necessary to provide strong evidence on this issue.

Although some kinds of supplementary methods were used during root canal retreatment to obtain clean root canals, neither one technique nor the combination of techniques has successfully removed RFM in root canals completely during retreatment (13, 16, 17, 50). Therefore, the present systematic review aimed to evaluate the effectiveness of supplementary approaches and techniques as adjunct treatment protocols to mechanical retreatment. Although further clinical studies are needed to establish the optimal approach to the application of supplementary techniques, this review identifies a research gap in the current literature and proposes directions for future clinical trials on the use of supplementary methods during root canal retreatment.

The limitations of this review were as follows: regarding the other supplementary methods with no suitable data for meta-analysis, findings were obtained from the cumulative outcomes. Furthermore, there was a great deal of heterogeneity among the included studies, such as in the filling technique, filling material, and parameters of the irrigation instruments. Therefore, studies of high methodological quality are needed to find definitive results in the future. On the other hand, this review included only *in vitro* studies. Although a well-designed experimental *in vitro* study may also provide strong evidence of clinical problems, clinical trials, such as randomized controlled trials, provide robust evidence. The third limitation is that some of the included studies did not have a priori sample size calculation. Therefore, it is possible that some of the studies that found no significant difference between the two methods made a type II error.

## CONCLUSION

Under *in vitro* conditions, UAI and the XPR increased the removal of RFM from the root canal system during retreatment procedures, and XPR had no significant superiority over UAI. In addition, strong evidence was found to support the increased cleaning efficiency of the supplementary use of GW, LAI, XPEF, and SAF, while conflicting evidence was found to support the use of sonic to improve the removal of RFM, and limited evidence was found to support the efficiency of TB.

## Disclosures

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