

## 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

Please cite this article as: Yang X, Lan J, Ji M, Tsauo C, Gao Y, Zou L. 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. *Eur Endod J* 2022; 7: 178-86

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Received 17 August 2021,  
Revised 08 March 2022,  
Accepted 30 May 2022

Published online: 12 September 2022  
DOI 10.14744/ej.2022.22932

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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

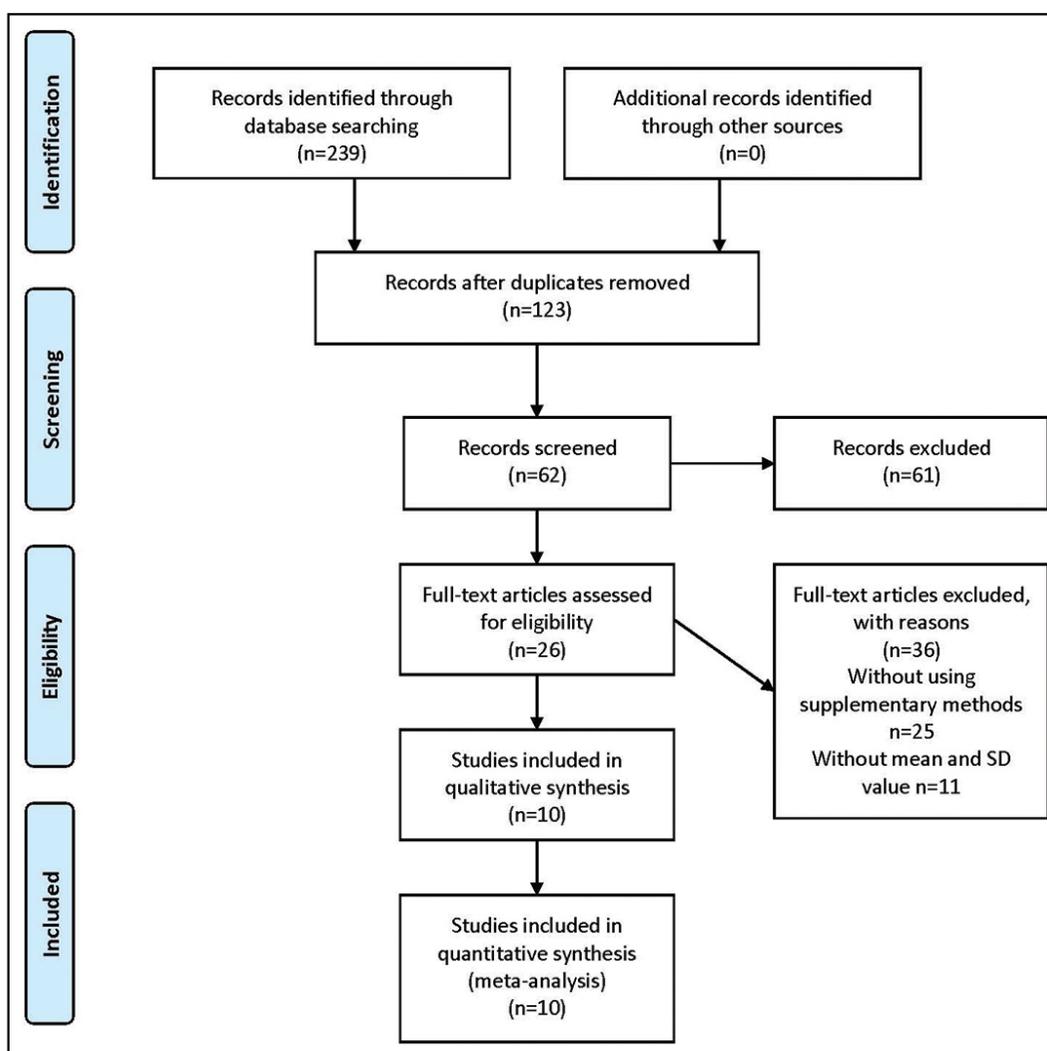


Figure 1. A flow chart of the literature search and the selection process according to the PRISMA statement

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)  | (Mtwo 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); Mtwo 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 (Step 1, 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 (PUJ)/RS: Reciproc 40+EndoActivator /ProTaper Next with Irrisonic Tip/ProTaper Next with EndoActivator; GP and Endofill with SC;0.40                    | PUJ 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/PUJ/H file); GP and AH Plus; 0.40/0.35/0.35   | XP-Endo Shaper, PUJ, #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. UAI showed better performance than GentleWave.                               |
| 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)                         | The additional use of PIPS for the activation of NaClO was superior to sonic and ultrasonic techniques in removing the remaining filling materials  |
| 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 lasers improved the removal of filling material.  |
| 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   |   |
| 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, PUJ: Passive ultrasonic irrigation

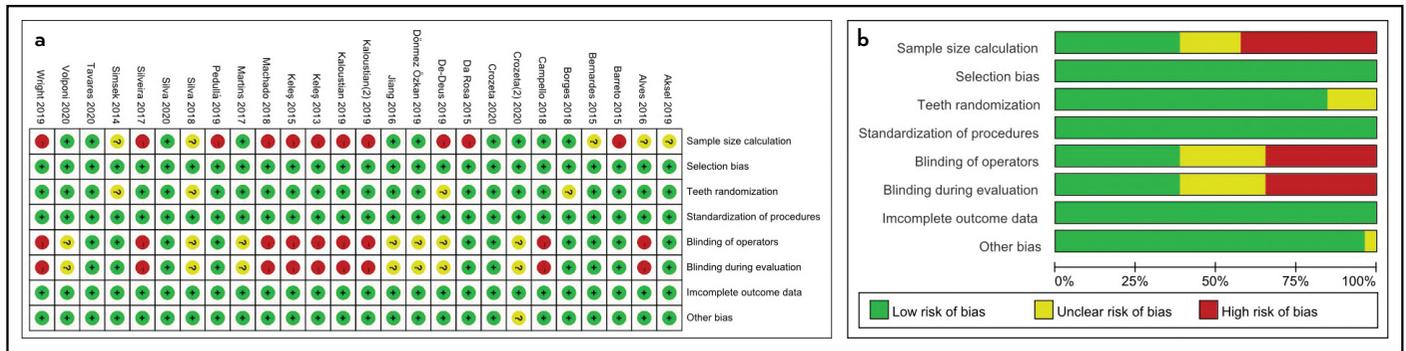


Figure 2. Risk of bias results of the included studies. (a) Risk of bias summary, (b) Risk of bias graph

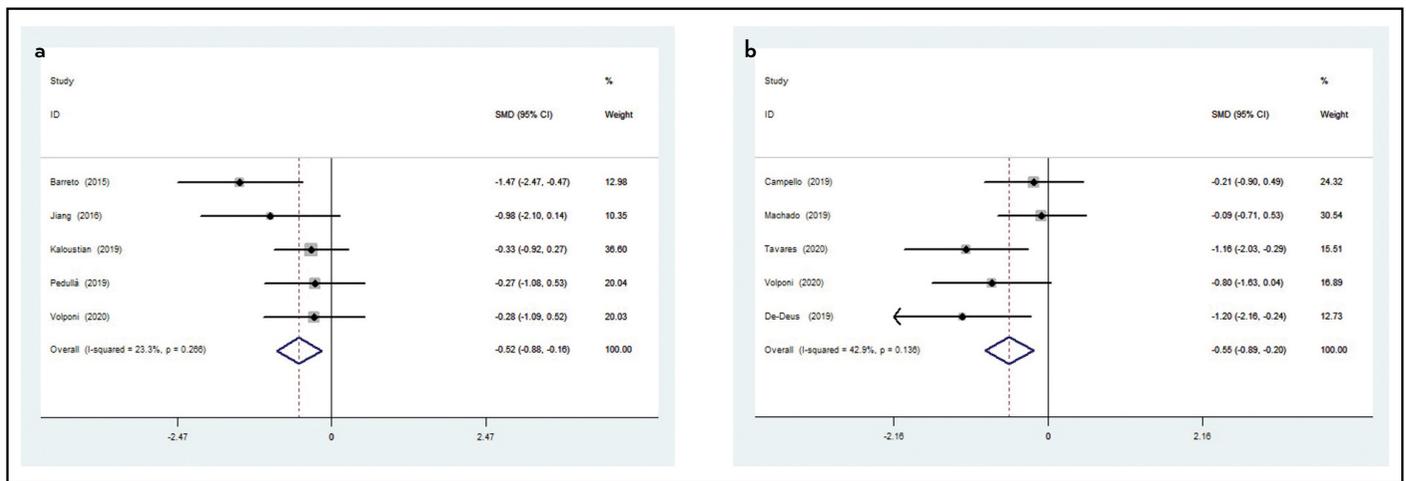


Figure 3. Forest plots of meta-analyses. (a) UAI, (b) XP-Endo finisher R  
UAI: Ultrasonically activated irrigation, SMD: Standardised mean difference, CI: Confidence interval

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

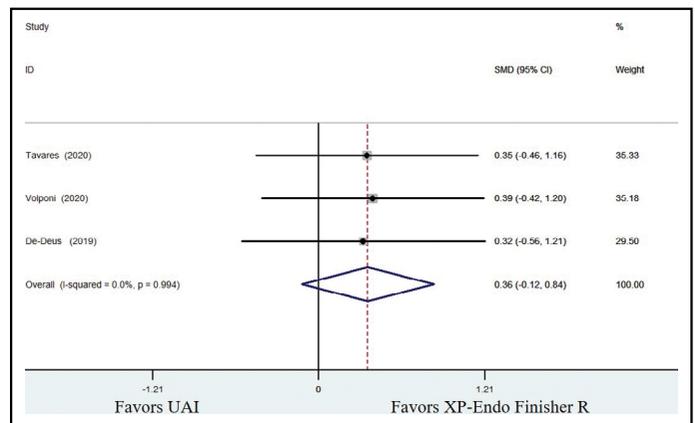


Figure 4. Forest plots of meta-analyses  
UAI: Ultrasonically activated irrigation, SMD: Standardised mean difference, CI: Confidence interval

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

**Conflict of interest:** The authors deny any conflict of interest.

**Ethics Committee Approval:** Not applicable.

**Peer-review:** Externally peer-reviewed.

**Financial Disclosure:** This study did not receive any financial support.

**Authorship contributions:** Concept – Y.G., L.Z.; Design – X.Y.; Supervision – Y.G., L.Z.; Funding - None; Materials - None; Data collection and/or processing – X.Y., J.L.; Analysis and/or interpretation – X.Y., J.L., M.J., C.T.; Literature search – X.Y., J.L., C.T.; Writing – X.Y., J.L., M.J., C.T.; Critical Review – Y.G., L.Z.

## REFERENCES

- McClanahan SB, Crepps JT, Maranga MC, Worrell DE, Behnia A. In: The AAE Board of Directors, editors. Glossary of Endodontic Terms. 10<sup>th</sup> ed. Chicago: American Association of Endodontists; 2020. p. 42.
- Ng YL, Mann V, Gulabivala K. A prospective study of the factors affecting outcomes of nonsurgical root canal treatment: part 1: periapical health. *Int Endod J* 2011; 44(7):583–609. [CrossRef]
- Endo MS, Ferraz CCR, Zaia AA, Almeida JFA, Gomes BPFA. Quantitative and qualitative analysis of microorganisms in root-filled teeth with persistent infection: Monitoring of the endodontic retreatment. *Eur J Dent* 2013; 7(3):302–9. [CrossRef]
- Kok D, Rosa RA, Barreto MS, Busanello FH, Santini MF, Pereira JR, et al. Penetrability of AH plus and MTA fillapex after endodontic treatment and retreatment: a confocal laser scanning microscopy study. *Microsc Res Tech* 2014; 77(6):467–71. [CrossRef]
- Good ML, McCammon A. An removal of gutta-percha and root canal sealer: a literature review and an audit comparing current practice in dental schools. *Dent Update* 2012; 39(10):703–8. [CrossRef]
- Ricucci D, Siqueira JF Jr, Bate AL, Pitt Ford TR. Histologic investigation of root canal-treated teeth with apical periodontitis: a retrospective study from twenty-four patients. *J Endod* 2009; 35(4):493–502. [CrossRef]
- Kfir A, Tsesis I, Yakirevich E, Matalon S, Abramovitz I. The efficacy of five techniques for removing root filling material: microscopic versus radiographic evaluation. *Int Endod J* 2012; 45(1):35–41. [CrossRef]
- Marfisi K, Mercade M, Plotino G, Duran-Sindreu F, Bueno R, Roig M. Efficacy of three different rotary files to remove gutta-percha and Resilon from root canals. *Int Endod J* 2010; 43(11):1022–8. [CrossRef]
- Mollo A, Botti G, Principi Goldoni N, Randellini E, Paragliola R, Chazine M, et al. Efficacy of two Ni-Ti systems and hand files for removing gutta-percha from root canals. *Int Endod J* 2012; 45(1):1–6. [CrossRef]
- Nevas G, de Albuquerque DS, Freire LG, Romeiro K, Fogel HM, Dos Santos M, et al. Efficacy of ProTaper NEXT compared with reciproc in removing obturation material from severely curved root canals: a micro-computed tomography study. *J Endod* 2016; 42(5):803–8. [CrossRef]
- De-Deus G, Belladonna FG, Zuolo AS, Cavalcante DM, Simões Carvalho M, Marinho A, et al. 3-dimensional ability assessment in removing root filling material from pair-matched oval-shaped canals using thermal-treated instruments. *J Endod* 2019; 45(9):135–41. [CrossRef]
- Rossi-Fedele G, Ahmed HM. Assessment of root canal filling removal effectiveness using micro-computed tomography: a systematic review. *J Endod* 2017; 43(4):520–6. [CrossRef]
- Crozeta BM, Silva-Sousa YT, Leoni GB, Mazzi-Chaves JF, Fantinato T, Baratto-Filho F, et al. Micro-computed tomography study of filling material removal from oval-shaped canals by using rotary, reciprocating, and adaptive motion systems. *J Endod* 2016; 42(5):793–7. [CrossRef]
- Hammad M, Qualtrough A, Silikas N. Three-dimensional evaluation of effectiveness of hand and rotary instrumentation for retreatment of canals filled with different materials. *J Endod* 2008; 34(11):1370–3. [CrossRef]
- Solomonov M, Paqué F, Kaya S, Adigüzel O, Kfir A, Yiğit-Özer S. Self-adjusting files in retreatment: a high-resolution micro-computed tomography study. *J Endod* 2012; 38(9):1283–7. [CrossRef]
- de Siqueira Zuolo A, Zuolo ML, da Silveira Bueno CE, Chu R, Cunha RS. Evaluation of the efficacy of TRUShape and reciproc file systems in the removal of root filling material: an *ex vivo* micro-computed tomographic study. *J Endod* 2016; 42(2):315–9. [CrossRef]
- Silva EJNL, Belladonna FG, Zuolo AS, Rodrigues E, Ehrhardt IC, Souza EM, et al. Effectiveness of XP-endo Finisher and XP-endo Finisher R in removing root filling remnants: a micro-CT study. *Int Endod J* 2018; 51(1):86–91.
- De-Deus G, Belladonna FG, Zuolo AS, Simões-Carvalho M, Santos CB, Oliveira DS, et al. Effectiveness of Reciproc Blue in removing canal filling material and regaining apical patency. *Int Endod J* 2019; 52(2):250–7.
- Silveira SB, Alves FRF, Marceliano-Alves MF, Sousa JCN, Vieira VTL, Siqueira JF Jr, et al. Removal of root canal fillings in curved canals using either mani GPR or HyFlex NT followed by passive ultrasonic irrigation. *J Endod* 2018; 44(2):299–303. [CrossRef]
- Fruchi Lde C, Ordinola-Zapata R, Cavenago BC, Hungaro Duarte MA, Bueno CE, De Martin AS. Efficacy of reciprocating instruments for removing filling material in curved canals obturated with a single-cone technique: a micro-computed tomographic analysis. *J Endod* 2014; 40(7):1000–4. [CrossRef]
- Bernardes RA, Duarte MAH, Vivan RR, Alcalde MP, Vasconcelos BC, Brantante CM. Comparison of three retreatment techniques with ultrasonic

- activation in flattened canals using micro-computed tomography and scanning electron microscopy. *Int Endod J* 2016; 49(9):890–7. [\[CrossRef\]](#)
22. Pedullà E, Abiad RS, Conte G, Khan K, Lazaridis K, Rapisarda E, et al. Retreatability of two hydraulic calcium silicate-based root canal sealers using rotary instrumentation with supplementary irrigant agitation protocols: a laboratory-based micro-computed tomographic analysis. *Int Endod J* 2019; 52(9):1377–87. [\[CrossRef\]](#)
  23. Crozeta BM, Lopes FC, Menezes Silva R, Silva-Sousa YTC, Moretti LF, Sousa-Neto MD. Retreatability of BC Sealer and AH Plus root canal sealers using new supplementary instrumentation protocol during non-surgical endodontic retreatment. *Clin Oral Investig* 2021; 25(3):891–9. [\[CrossRef\]](#)
  24. Alves FR, Marceliano-Alves MF, Sousa JC, Silveira SB, Provenzano JC, Siqueira JF Jr. Removal of root canal fillings in curved canals using either reciprocating single- or rotary multi-instrument systems and a supplementary step with the XP-Endo Finisher. *J Endod* 2016; 42(7):1114–9.
  25. Da Rosa RA, Santini MF, Cavenago BC, Pereira JR, Duarte MA, Só MV. Micro-CT evaluation of root filling removal after three stages of retreatment procedure. *Braz Dent J* 2015; 26(6):612–8. [\[CrossRef\]](#)
  26. Kaloustian MK, Nehme W, El Hachem C, Zogheib C, Ghosn N, Michetti J, et al. Evaluation of two shaping systems and two ultrasonic irrigation devices in removing root canal filling material from mesial roots of mandibular molars: a micro CT study. *Dent J (Basel)* 2019; 7(1):2. [\[CrossRef\]](#)
  27. Jiang S, Zou T, Li D, Chang JW, Huang X, Zhang C. Effectiveness of sonic, ultrasonic, and photon-induced photoacoustic streaming activation of NaOCl on filling material removal following retreatment in oval canal anatomy. *Photomed Laser Surg* 2016; 34(1):3–10. [\[CrossRef\]](#)
  28. Crozeta BM, Chaves de Souza L, Correa Silva-Sousa YT, Sousa-Neto MD, Jaramillo DE, Silva RM. Evaluation of passive ultrasonic irrigation and GentleWave system as adjuvants in endodontic retreatment. *J Endod* 2020; 46(9):1279–85. [\[CrossRef\]](#)
  29. Borges MMB, Duque JA, Zancan RF, Vivan RR, Bernardes RA, Duarte MAH. Efficacy of reciprocating systems for removing root filling material plus complementary cleaning methods in flattened canals: Microtomography and scanning electron microscopy study. *Microsc Res Tech* 2019; 82(7):1057–64. [\[CrossRef\]](#)
  30. Martins MP, Duarte MA, Cavenago BC, Kato AS, da Silveira Bueno CE. Effectiveness of the ProTaper Next and Reciproc systems in removing root canal filling material with sonic or ultrasonic irrigation: a micro-computed tomographic study. *J Endod* 2017; 43(3):467–71. [\[CrossRef\]](#)
  31. Kaloustian MK, Nehme W, El Hachem C, Zogheib C, Ghosn N, Mallet JP, et al. Evaluation of two shaping systems and two sonic irrigation devices in removing root canal filling material from distal roots of mandibular molars assessed by micro CT. *Int Endod J* 2019; 52(11):1635–44. [\[CrossRef\]](#)
  32. Wright CR, Glickman GN, Jalali P, Umoren M. Effectiveness of Gutta-percha/Sealer removal during retreatment of extracted human molars using the GentleWave system. *J Endod* 2019; 45(6):808–12. [\[CrossRef\]](#)
  33. Keleş A, Arslan H, Kamalak A, Akçay M, Sousa-Neto MD, Versiani MA. Removal of filling materials from oval-shaped canals using laser irradiation: a micro-computed tomographic study. *J Endod* 2015; 41(2):219–24.
  34. Dönmez Özkan H, Kaval ME, Özkan G, Yiğit Özer S. Efficacy of two different Nickel-Titanium rotary systems in retreatment procedure with or without laser-activated irrigation: an *in vitro* study. *Photobiomodul Photomed Laser Surg* 2019; 37(8):495–9. [\[CrossRef\]](#)
  35. De-Deus G, Belladonna FG, Zuolo AS, Cavalcante DM, Carvalho JCA, Simões-Carvalho M, et al. XP-endo Finisher R instrument optimizes the removal of root filling remnants in oval-shaped canals. *Int Endod J* 2019; 52(6):899–907. [\[CrossRef\]](#)
  36. Keleş A, Alcin H, Kamalak A, Versiani MA. Oval-shaped canal retreatment with self-adjusting file: a micro-computed tomography study. *Clin Oral Investig* 2014; 18(4):1147–53. [\[CrossRef\]](#)
  37. Campello AF, Almeida BM, Franzoni MA, Alves FRF, Marceliano-Alves MF, Rôças IN, et al. Influence of solvent and a supplementary step with a finishing instrument on filling material removal from canals connected by an isthmus. *Int Endod J* 2019; 52(5):716–24. [\[CrossRef\]](#)
  38. Aksel H, Küçükkaya Eren S, Askerbeyli Örs S, Serper A, Ocak M, Çelik HH. Micro-CT evaluation of the removal of root fillings using the ProTaper Universal Retreatment system supplemented by the XP-Endo Finisher file. *Int Endod J* 2019; 52(7):1070–6. [\[CrossRef\]](#)
  39. Simsek N, Ahmetoglu F, Keles A, Bulut ET, Er K. 3D analysis of D-RaCe and self-adjusting file in removing filling materials from curved root canals instrumented and filled with different techniques. *ScientificWorldJournal* 2014; 2014:836513. [\[CrossRef\]](#)
  40. Tavares SJO, Gomes CC, Marceliano-Alves MF, Guimaraes LC, Provenzano JC, Amoroso-Silva P, et al. Supplementing filling material removal with XP-Endo Finisher R or R1-Clearsonic ultrasonic insert during retreatment of oval canals from contralateral teeth. *Aust Endod J* 2021; 47(2):188–94.
  41. Silva PA, Alcalde MP, Vivan RR, Duarte MAH. Comparison of the Self-adjusting file and Hedström file used as supplementary instruments for the remaining filling material removal during retreatment of C-shaped canals: a micro-CT study. *Eur Endod J* 2020; 5(2):112–7. [\[CrossRef\]](#)
  42. Silva EJNL, Prado MC, Soares DN, Hecksher F, Martins JNR, Fidalgo TKS. The effect of ozone therapy in root canal disinfection: a systematic review. *Int Endod J* 2020; 53(3):317–32. [\[CrossRef\]](#)
  43. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ* 2003; 327(7414):557–60. [\[CrossRef\]](#)
  44. Barreto MS, Rosa RA, Santini MF, Cavenago BC, Duarte MA, Bier CA, et al. Efficacy of ultrasonic activation of NaOCl and orange oil in removing filling material from mesial canals of mandibular molars with and without isthmus. *J Appl Oral Sci* 2016; 24(1):37–44. [\[CrossRef\]](#)
  45. Volponi A, Pelegrine RA, Kato AS, Stringheta CP, Lopes RT, Silva ASS, et al. Micro-computed tomographic assessment of supplementary cleaning techniques for removing bioceramic sealer and Gutta-percha in oval canals. *J Endod* 2020; 46(12):1901–6. [\[CrossRef\]](#)
  46. Cavenago BC, Ordinola-Zapata R, Duarte MA, del Carpio-Perochena AE, Villas-Bôas MH, Marciano MA, et al. Efficacy of xylene and passive ultrasonic irrigation on remaining root filling material during retreatment of anatomically complex teeth. *Int Endod J* 2014; 47(11):1078–83. [\[CrossRef\]](#)
  47. Machado AG, Guilherme BPS, Provenzano JC, Marceliano-Alves MF, Gonçalves LS, Siqueira JF Jr, et al. Effects of preparation with the Self-Adjusting File, TRUShape and XP-endo Shaper systems, and a supplementary step with XP-endo Finisher R on filling material removal during retreatment of mandibular molar canals. *Int Endod J* 2019; 52(5):709–15.
  48. Goode N, Khan S, Eid AA, Niu LN, Gosier J, Susin LF, et al. Wall shear stress effects of different endodontic irrigation techniques and systems. *J Dent* 2013; 41(7):636–41. [\[CrossRef\]](#)
  49. Uzunoglu-Özyürek E, Küçükkaya Eren S, Karahan S. Contribution of XP-Endo files to the root canal filling removal: A systematic review and meta-analysis of *in vitro* studies. *Aust Endod J* 2021; 47(3):703–14. [\[CrossRef\]](#)
  50. Sousa-Neto MD, Silva-Sousa YC, Mazzi-Chaves JF, Carvalho KKT, Barbosa AFS, Versiani MA, et al. Root canal preparation using micro-computed tomography analysis: a literature review. *Braz Oral Res* 2018; 32(suppl 1):e66. [\[CrossRef\]](#)