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Effectiveness, efficiency, and apical extrusion of 2 rotaries and 2 reciprocating systems in removing filling material during endodontic retreatment. A systematic review

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Abstract

Background: This systematic review investigated the effectiveness, efficiency and apical extrusion of the debris of two rotary and two reciprocating single-file systems used for the removal of filling material from straight root canals.

Material and Methods: A literature search was performed in the Medline, ISI Web of Science, and Scopus databases for relevant articles matching the keyword search strategy. Effectiveness was determined with studies dealing with the ability of the instruments to remove filling material from root canals. Efficiency was assessed with studies dealing with the time needed to completely remove the root canal filling, and apical extrusion was determined with studies that measured the amount of filling material extruded through the apex.

Results: From the 424 articles initially found, 406 were excluded for being non-relevant or not fulfilling the selection criteria. Another 9 articles were excluded after methodology evaluation. Finally, 9 studies were included in the systematic review.
Conclusions: None of the reviewed systems is effective to completely remove the filling materials from straight root canals, and all systems appear to be equally time-efficient, although this variable shows different results. In terms of apical extrusion, the analyzed reciprocating systems extrude more material toward the periapical tissues than the continuous rotation systems.

Key words: *Systematic review, rotary files, reciprocating files, apical extrusion, endodontic retreatment.*

Introduction

Endodontic retreatment could be challenging within the endodontic practice, mainly due to difficulties for the removal of contaminated materials from the root canal system without extruding them to the periapical tissues. Therefore, several studies have been addressed to analyze the effectiveness and efficiency of endodontic instruments to achieve this purpose; as well as the periapical extrusion of debris and filling materials (1).
It is highly relevant to combine the three aforementioned variables (effectiveness, efficiency, and apical extrusion of debris) and analyze them in studies dealing with the removal of filling materials. Effectiveness is defined as the ability of an instrument to remove the filling material from the root canal system; efficiency refers to the patients' chair-time required to perform the complete removal of the material, and apical extrusion of debris deals with the amount of material pushed by the endodontic instruments through the apical foramen into the periapical tissues during endodontic retreatment (2-4).
The main purpose of endodontic retreatment is to alleviate signs and symptoms related to infectious processes by completely removing the intra-canal filling materials from the involved root, and reduce the intra-canal bacterial load after performing an adequate protocol of cleaning and disinfection of the canal to reestablish healthy periapical tissues (5). However, it has been shown that retreatment does not guarantee total elimination of the intra-canal bacteria and that the overall reported success rate of endodontic retreatment is around 78%, in contrast to first-time conventional endodontic treatment where success range between 86% and 96% in necrotic and vital teeth, respectively (6).
To perform a more effective, efficient, and less invasive procedure in terms of apical extrusion of debris and materials, engine-driven rotatory techniques specially designed for endodontic retreatments such as Protaper Universal Retreatment system and Mtwo retreatment system have been proposed.
Recently, single-file nickel-titanium (Ni-Ti) reciprocating systems like WaveOne (Dentsply Maillefer, Ballaigues-Switzerland) and Reciproc (VDW, Munich, Germany) have been used for endodontic retreatment, even though they were not designed for such purpose. However, they have shown positive results in terms of effectiveness and efficiency during these types of procedures (7).
These system´s philosophy proposes a single-file endodontic treatment, which renders the endodontic retreatment to be time reduced. However, it has been shown that these files, are incapable of completely remove the filling material from the root canals. Moreover, it has been demonstrated that they cause greater extrusion of materials toward the periapical tissues than continuous rotation file systems (3,7).
Considering all the above, a systematic review of the literature was conducted following AMSTAR, PRISMA and Faggion guidelines (8-10), analyzing the effectiveness, efficiency and apical extrusion of two continuous rotation systems (Protaper Universal and Mtwo retreatment systems) and two single-file reciprocating systems (Wave One and Reciproc) to determine which one is the more efficient and effective and which one extrudes less amount of filling material during endodontic retreatment.

Material and Methods

-Information sources and search strategy:
Several keywords were used for each one of the elements of interest:
1): (Retreatment OR endodontic retreatment OR endodontic failures OR endodontic retreatment success OR endodontic retreatment techniques OR filling material removal OR nonsurgical Retreatment);
2): (Rotary systems OR rotary file OR Protaper universal retreatment system OR Mtwo retreatment system);
3): (Reciprocating systems OR reciprocating instruments OR Reciproc OR WaveOne).
The electronic search of the literature has been conducted in the following databases: MEDLINE, ISI WEB OF SCIENCE and SCOPUS; using the following keyword combinations: 1 AND 2 and, 1 AND 3, and the following filters: AND humans, AND English AND 2010/01/01-2022/07/25 without filtering by journal. Table 1 shows the search strategy used for each database.

Table 1: Database search strategy.

Database		Search Strategy	Items Found
MEDLINE	1 AND 2	((("retreatment"[MeSH Terms] OR "retreatment"[All Fields]) OR (endodontic[All Fields] AND ("retreatment"[MeSH Terms] OR "retreatment"[All Fields])) OR (endodontic[All Fields] AND failures[All Fields]) OR (endodontic[All Fields] AND ("retreatment"[MeSH Terms] OR "retreatment"[All Fields]) AND success[All Fields]) OR (endodontic[All Fields] AND ("retreatment"[MeSH Terms] OR "retreatment"[All Fields]) AND ("methods"[Subheading] OR "methods"[All Fields] OR "techniques"[All Fields] OR "methods"[MeSH Terms] OR "techniques"[All Fields])) OR (filling[All Fields] AND material[All Fields] AND removal[All Fields]) OR (nonsurgical[All Fields] AND ("retreatment"[MeSH Terms] OR "retreatment"[All Fields])))) AND (((rotary[All Fields] AND systems[All Fields]) OR (rotary[All Fields] AND ("filing"[MeSH Terms] OR "filing"[All Fields] OR "file"[All Fields])) OR (Protaper[All Fields] AND universal[All Fields] AND ("retreatment"[MeSH Terms] OR "retreatment"[All Fields]) AND system[All Fields]) OR (mtwo[All Fields] AND ("retreatment"[MeSH Terms] OR "retreatment"[All Fields]) AND system[All Fields]))) Filters: Humans, English, from 2010/1/1 - 2022/7/25	241
	1 AND 3	((("retreatment"[MeSH Terms] OR "retreatment"[All Fields]) OR (endodontic[All Fields] AND ("retreatment"[MeSH Terms] OR "retreatment"[All Fields])) OR (endodontic[All Fields] AND failures[All Fields]) OR (endodontic[All Fields] AND ("retreatment"[MeSH Terms] OR "retreatment"[All Fields]) AND success[All Fields]) OR (endodontic[All Fields] AND ("retreatment"[MeSH Terms] OR "retreatment"[All Fields]) AND ("methods"[Subheading] OR "methods"[All Fields] OR "techniques"[All Fields] OR "methods"[MeSH Terms] OR "techniques"[All Fields])) OR (filling[All Fields] AND material[All Fields] AND removal[All Fields]) OR (nonsurgical[All Fields] AND ("retreatment"[MeSH Terms] OR "retreatment"[All Fields])))) AND (((reciprocating[All Fields] AND systems[All Fields]) OR (reciprocating[All Fields] AND ("instrumentation"[Subheading] OR "instrumentation"[All Fields] OR "instruments"[All Fields])) OR Reciproc[All Fields] OR WaveOne[All Fields])) Filters: Humans, English, from 2010/1/1 - 2022/7/25	156
ISI WEB OF SCIENCE	1 AND 2	((((TS=((retreatment OR endodontic retreatment OR endodontic failures OR endodontic retreatment success OR endodontic retreatment techniques OR filling material removal OR nonsurgical Retreatment)))) AND TS=((rotary systems OR rotary file OR protaper universal retreatment system OR mtwo retreatment system))) AND TS=(Humans)) AND LA=(English) *Timespan: 2010-01-01 to 2022-07-25 (Index Date)*	108
	1 AND 3	(((TS=((retreatment OR endodontic retreatment OR endodontic failures OR endodontic retreatment success OR endodontic retreatment techniques OR filling material removal OR nonsurgical Retreatment))) AND TS=((reciprocating systems OR reciprocating instruments OR reciproc OR waveone))) AND TS=(Humans)) AND LA=(English) *Timespan: 2010-01-01 to 2022-07-25 (Index Date)*	40
SCOPUS	1 AND 2	(TITLE-ABS-KEY ((retreatment OR endodontic AND retreatment OR endodontic AND failures OR endodontic AND retreatment AND success OR endodontic AND retreatment AND techniques OR filling AND material AND removal OR nonsurgical AND retreatment)) AND TITLE-ABS-KEY ((rotary AND systems OR rotary AND file OR protaper AND universal AND retreatment AND system OR mtwo AND retreatment AND system)) AND TITLE-ABS-KEY (humans) AND LANGUAGE (english)) AND PUBYEAR > 2009 AND PUBYEAR < 2023 AND PUBYEAR > 2009 AND PUBYEAR < 2023	26
	1 AND 3	(TITLE-ABS-KEY ((retreatment OR endodontic AND retreatment OR endodontic AND failures OR endodontic AND retreatment AND success OR endodontic AND retreatment AND techniques OR filling AND material AND removal OR nonsurgical AND retreatment)) AND TITLE-ABS-KEY ((reciprocating AND systems OR reciprocating AND instruments OR reciproc OR waveone)) AND TITLE-ABS-KEY (humans) AND LANGUAGE (english)) AND PUBYEAR > 2009 AND PUBYEAR < 2023 AND PUBYEAR > 2009 AND PUBYEAR < 2023	19

An additional manual search was also performed, searching for:
a) Titles in the bibliographic references of the selected articles, unidentified by the method described above and;
b) In-press articles in 4 high-impact Endodontic Journals (International Endodontic Journal, Journal of Endodontics, Australian Endodontic Journal and Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics).
-Extraction of the information:
From the selected studies, the following criteria were extracted: Authors, name, and ranking of the journal where the study was published, title, year of publication, type of study, sample size and characteristics, randomization, biases, endodontic filling removal technique, variables, units of measurement, evaluation method, statistical analysis, level of significance and results (Table 2-2 cont.-3). These data allowed submitting each study to the analysis of the methodological quality and classifying them according to the level of evidence (Table 3).

Results

-Selection of the studies:
The electronic search (Fig. 1) was performed on 2022/07/25 following the flow diagram suggested by PRISMA (11). In the MEDLINE database, 241 results were obtained with the combination of criteria 1 AND 2, and 156 results with the combination of 1 AND 3. In ISI WEB OF SCIENCE, for the same combinations, the results obtained were 108 and 40 respectively. Finally, in the Scopus database, 26 and 19 results were obtained for the same combinations, for a total of 590 articles.
Removing duplicates for searches 1 AND 2 and 1 AND 3, a total of 412 articles were obtained. Additionally, 12 articles from the manual search were included for a total of 424 studies. Three reviewers (J.C., C.G., and N.R.) independently reviewed the titles, abstracts, and full-texts (in cases where there was no abstract) considering the established selection criteria (Table 4). This process allowed the exclusion of 406 articles: 257 for being irrelevant and 149 by exclusion criteria. Finally, 18 studies were chosen. In case of disagreement between the reviewers, the decisions were made by consensus. A further evaluation of the materials and methods was conducted on the selected articles, allowing the exclusion of 9 studies (12-20) due to methodological criteria (Table 5), for a final number of 9 studies selected (Fig. 1).
A total of 9 *in vitro* articles (3,4,7,21-26) were included in the systematic review (Fig. 1). Analysis of these studies demonstrates that the evaluated systems (continuous and reciprocating) are ineffective for the complete removal of the filling material from straight root canals (23). Ríos *et al*. concluded that the WaveOne and Reciproc systems are more effective for removing the filling materials (7); while Akbulut *et al*. concluded that there is no statistically significant difference between Protaper Universal Retreatment system and Reciproc (22). Moreover, Monguilhott Crozeta *et al*. reported that the Protaper Universal Retreatment system and Reciproc displayed similar volumes of residual material within the analyzed root canals (24).
Regarding the efficiency of the systems to remove the filling material from straight root canals, Özyürek & Demiryürek found that the Protaper Universal Retreatment system is significantly faster and even more effective than the Reciproc system (25). However, Dincer *et al*. concluded that the Protaper Universal Retreatment system and Reciproc are equally efficient and both require less time to remove gutta-percha than the Mtwo retreatment system (21).
Finally, regarding apical extrusion of filling material, Lu *et al*. concluded that Reciproc extrudes more material than the Mtwo Retreatment system, since continuous rotation promotes the transport of the endodontic materials toward the coronal tooth portion, while the reciprocating movement favors the instrument to push the filling material residues toward the apex (3). Likewise, the study by Silva *et al*. reported that there are no differences between Reciproc and WaveOne in terms of apical extrusion of filling materials and debris and that the apical extrusion of material occurs independently of the retreatment system used, as all of them produce at least a minimum of material and debris extrusion toward the apex (4).

Discussion

This systematic review evaluates the effectiveness, efficiency and the apical extrusion of filling material of two rotary retreatment systems (Protaper Universal Retreatment and Mtwo retreatment systems) compared to two reciprocating systems (Reciproc and WaveOne), for removing gutta-percha from straight root canals. These systems were selected because there are not enough studies published from other retreatment systems to analyze the data under similar conditions.
In vitro research on natural teeth evaluating new materials and techniques for subsequent *In vivo* human use is an important issue of modern dentistry since this type of studies can be conducted under controlled conditions; therefore, *In vitro* studies conducted on natural human teeth were established as essential inclusion criteria, although *in vitro* studies cannot reproduce a dynamic clinical setting (10). The use of freshly extracted human teeth allows operators to simulate clinical endodontic procedures as close as possible to reality (7), and considering several aspects such as similarities regarding clinical environment conditions, hardness, elasticity, humidity, and natural consistency of the dentin, allow achieving a well-structured analogy of the management of human root canals (27).

Table 2: Articles included in the systematic review.

Authors / Year	Study type	Sample Description	Sample Size	Randomization	Preparation Method	Method for removing filling material	Variables	Measurement units	Evaluation Mehtod	Bias	Statistical Analysis	Results
Lu *et al.* 2013 [3]	Experimental *In vitro*	Freshly extracted human teeth, straight roots (less than 5°), preservation method: 37°C-100% humidity for 7 days, crowns sectioned (root= 14mm).	60 lower premolars	G1: 20 teeth, Reciproc (R40) G2: 20 teeth, Mtwo Retreatment System (R15, R25). G3: 20 teeth, control group Hedstrom.	Working length: 1 mm from apical foramen with 10 K-file. Instruments: K files with step-back technique. Master file: #35. Irrigation: NaOCl. Obturation: Guttapercha/AHPlus. Preservation: 37°, 100% humidity for 7 days.	Reciproc (R40), Mtwo Retreatment (R15, R25), Hedstrom (15-40). Irrigation: NaOCl.	Efficiency, Apical extrusion	Seconds, weight	Chronometer, Myers & Montgomery method with a precision analytical microbalance	Random sampling, tooth preparation and retreatment were carried out by different operators. The measurement of apically extruded debris and irrigant was carried out by a third person. Double blind study.	One-way Anova, no post hoc test. (p<.05)	Both the Reciproc® R40 system and the Mtwo Retreatment System extrude less material than the Hedstrom files at retreatment procedures.
Rios *et al.* 2014 [7]	Experimental *In vitro*	Samples from human teeth bank, uniradicular, straight roots, complete apex formation, preservation medium: 0.1% thymol before use, crowns sectioned (root= 16 mm).	60 upper central incisors	G1: 20 teeth, Reciproc (R25) G2: 20 teeth, WaveOne (Primary) G3: 20 teeth, Protaper Universal Retreatment (D1, D2, D3)	Working length: 1 mm from apical foramen. Instruments: Protaper Universal (SX, S1, S2 and F1, F2, F3, F4), Gates Glidden 2,3,4. Master file: #40. Irrigation: NaoCl, EDTA 3min, NaOCl, Obturation: AH-Plus / Gutapercha cones, Obtura II. Preservation: 37 °, 100% humidity for 30 days	Reciproc (R25), WaveOne (Primary), Protaper Universal retreatment (D1, D2, D3), without solvents, until residual material was not observed. Irrigation: NaoCl, EDTA 3min, NaoCl.	Effectiveness	mm3 percentage	digital photography under magnification	Random sampling, 1 single operator. Blinding not specified.	One-way Anova.. No post hoc. (p <.05)	Reciproc left more residual material within the root canals than WaveOne and Protaper Universal Retreatment System. No statistically significant differences found between groups

Table 2 cont.: Articles included in the systematic review.

Silva *et al.* 2014 [4]	Experimental *In vitro*	Extracted human teeth, straight roots (less than 10 °), disinfected: 0.5% chloramine T, preservation medium: distilled water, storage for 6 months until use.	45 lower premolars	G1: 15 teeth, Protaper Universal Retreatment System (D1, D2, D3, F2, F3, F4) G2: 15 teeth, Reciproc (R25-R40) G3: 15 teeth, WaveOne (Primary - large)	Working length: 1mm from apical foramen with 15 K-file. Instruments: Protaper Universal (SX, S1, S2, F1, F2, F3. Irrigation: NaoCl 1ml, 3ml EDTA 3min, 1ml NaoCl. Obturation: AH-Plus / Protaper F3 Gutapercha Cones. Preservation: 37°, 100% humidity for 30 days	Protaper Universal Retreatment (D1, D2, D3, F2, F3, F4), Reciproc (R25, R40), WaveOne (Primary and large), without solvents. Irrigation: NaoCl, EDTA x 3min, NaOCl.	Apical extrusion	Weight	Myers & Montgomery method with a precision analytical microbalance	random sampling, 1 single operator. All plastic assay tubes were covered with black tape to blind the operator. blind study	One-way Anova, Tukey post-hoc test. (p <.05)	Protaper Universal Retreatment System extruded significantly more material than Reciproc (R25, R40) and WaveOne (Primary and large). No statistically significant differences found between reciprocating and rotary systems.
Dincer *et al.* 2015 [21]	Experimental *In vitro*	Freshly extracted human teeth (periodontal reasons), preservation medium not specified.	60 lower incisors	G1: 15 teeth, Protaper Universal Retreatment System (D1, D2, D3) G2: 15 teeth, Mtwo Retreatment System (R15, R25) G3: 15 teeth, Reciproc (R25) G4: 15 teeth, Hedstrom files (25,30,35) and Gates Glidden.	Working length: 1mm from apical foramen with 10 K-file. Instruments: Reciproc R25. Preservation: 37° C and 100% humidity for 8 weeks.	Protaper Universal Retreatment (D1, D2, D3), Mtwo Retreatment (25/.05, 15/.05), Reciproc (R25). Gates Glidden (1, 2, 3) and Hedstrom files 35,30,25. Irrigation: distilled water.	Efficiency, Apical extrusion	Seconds, weight	Chronometer, Myers & Montgomery method with a precision analytical microbalance	Random sampling, no operators or blinding specified	One-way Anova, Tukey post-hoc test; Student-Newman-Keuls post-hoc test. (p<.05)	Reciproc R25 extruded significantly less material than Mtwo, Protaper Universal Retreatment System and H-files. No significant differences between Mtwo R, Protaper R and H-file.

Table 2 cont.-1: Articles included in the systematic review.

Akbulut *et al.* 2016 [22]	Experimental *In vitro*	Extracted human teeth, preservation medium: NaOCl, crowns sectioned (root= 16mm).	60 uniradicular teeth	G1: 15 teeth, TF Adaptive (ML2, ML3). G2: 15 teeth, Reciproc (R50). G3: 15 teeth, Protaper Universal Retreatment System (D1, D2, D3, F4, F5). G4: 15 teeth, Hedstrom.	Working length: 1mm from apical foramen. Instruments: Protaper (F4). Master file: # 40. Irrigation: 1 mL of NaOCl, EDTA, NaOCl. Obturation: Guttapercha/AH-Plus. Preservation: 37° C and 100% humidity for 4 weeks.	TF Adaptive (ML2, ML3), Reciproc (R50), Protaper Universal retreatment (D1, D2, D3, F4, F5), Hedstrom (40.35.30), K Files # 50, without solvents. Irrigation: NaOCl.	Effectiveness Efficiency	mm3, seconds	CBCT, chronometer	Random sampling. all images were assessed by 2 observers. Blinding not specified	Anova test, Tukey post-hoc test. (p<.05)	Reciproc and ProTaper Universal Retreatment system removed filling material more efficiently than TF Adaptive and hand files. The TF Adaptive system was more efficient than hand files.
Crozeta *et al.* 2016 [23]	Experimental *In vitro*	Samples from human teeth bank, straight roots, preservation medium: 1% thymol, crowns sectioned (root= 14mm).	21 lower molars	G1: 7 teeth, Protaper Universal retreatment system (D1, D2, D3, F2, F3, F4, F5), G2: 7 teeth, Reciproc (R50), G3: 7 teeth, TF Adaptive.	Working length: 1mm from apical foramen with 10 K-file. Instruments: K3 #25/.08, #25/.06 #25/.04 and #25, #30, #35, #40. Master file: # 40. Irrigation: NaOCl, EDTA 5 min, distilled water. Obturation: Guttapercha/AH-Plus. Preservation: 37° C and 100% humidity for 2 weeks.	Protaper Universal Retreatment (D1, D2, D3, F2, F3, F4, F5), Reciproc (R50), TF Adaptive (50/.04), without solvents. Irrigation: NaOCl.	Effectiveness	mm3	Micro-CT	Random sampling, 1 single operator. Blinding not specified	One-way Anova, tukey post-hoc tesy (p<.05)	TF Adaptive showed the lower percentage of removed filling material. Protaper Universal Retreatment System and Reciproc left residual material in the canal.
Monguilhott Crozeta *et al.* 2016 [24]	Experimental *In vitro*	Samples from human teeth bank, straight roots, preservation and disinfection	42 lower molars	G1: 7 teeth, Protaper Universal retreatment system (D1, D2, D3, F2, F3, F4).	Working length: 1 mm from apical foramen, with 10 K-file. Instruments: Gates Glidden (1,2,3) K files	Reciproc (R40), Mtwo Retreatment (R15, R25),	Effectiveness	mm3	Micro-CT	Random sampling, 1 operator performed all the procedures. Blinding not specified	One-way Anova test and Least significant difference (LSD) post	Residual filling material was observed in all the specimens. There were

Table 2 cont.-2: Articles included in the systematic review.

		methods not specified, crowns sectioned (root= 14mm).		G2: 7 teeth, WaveOne (Large). G3: 7 teeth, Reciproc (R40). G4: 7 teeth, Reciproc (R50). G5: 7 teeth, WaveOne (Primary, Large). G6: 7 teeth Reciproc (R25 / R40 / R50).	with step-down technique. Master file: #40. Irrigation: NaOCl, EDTA 5 min, distilled water. Obturation: Guttapercha/AH-Plus. Preservation: 100% humidity at 37 ° C for 2 weeks.	Hedstrom (15-40). Irrigation: NaOCl.					hoc-test (p<.05)	less remnant material in the WaveOne Large and Reciproc R50 groups, and in the Reciproc R25, R40 and R50 groups compared to the WaveOne Primary and Large group. The Protaper Universal Retreatment System and Reciproc R40 groups showed similar results regarding filling material remnants compared to the other groups.
Özyürek & Demiryürek 2016 [25]	Experimental *In vitro*	Extracted human teeth (periodontal reasons), straight roots, preservation medium: distilled water 4°C, crown sectioned (root= 20 mm).	80 upper central incisors	G1: 20 teeth, Protaper Next (X2, X3, X5). G2: 20 teeth, TF Adaptive (ML2, ML1, ML3). G3: 20 teeth, Reciproc (R25). G4: 20 teeth, Protaper Universal	Working length: 1mm from apical foramen with 10 K-files Instruments: K-files with a crown-down technique. Master file: #40. Irrigation: NaOCl, EDTA 17%, distilled water. Obturation: Guttapercha / AH-Plus. Preservation: 37°, 100% humidity for 14 days.	Protaper Next (X2, X3, X5), TF Adaptive (ML2, ML1, ML3), Reciproc (R25), Protaper Universal Retreatment (D1, D2, D3, F5), without solvents.	Effectiveness Efficiency	mm3, seconds	Stereomicroscope attached to a digital camera, chronometer	Random sampling, 1 operator performed all the procedure. Blinding not specified	One-way Anova, 2-way Anova and Duncan's post-hoc test (p<.05)	The total retreatment time was significantly shorter in the Protaper Universal Retreatment System group compared to Protaper Next, TF Adaptive and Reciproc. There was a significant difference between the

Table 2 cont.-3: Articles included in the systematic review.

				Retreatment System (D1, D2, D3, F5)		Irrigation: NaOCl, EDTA 2 min, NaOCl, distilled water.						groups in terms of total gutta-percha and sealer residues
Bago et al. 2019 [26]	Experimental *In vitro*	Extracted human teeth, single straight roots preservation method not specified. Crowns sectioned (root = 15 mm)	45 premolars	G1: 15 teeth, Reciproc Blue (R40) G2: 15 teeth. Reciproc (R40) G3: 15 teeth. Protaper Universal Retreatment System (D1, D2, D3, X3, X4)	Working length: 1mm from apical foramen,, with 10 K-file. Instruments: Protaper Next (X1, X2, and X3. Master File: #30, .07. Irrigation: NaOCl, EDTA for 1min, NaOCl, and saline solution. Obturation: Guttapercha/AH-plus. Preservation: 37°C and 100% relative humidity for 1 month.	Reciproc Blue System: (R40) Reciproc System: (R40) Protaper Universal Retreatment System: (D1, D2, D3, X3 and X4). Retreatment was considered complete when each instrument reached WL five times. Irrigation: NaoCl, EDTA3min , NaOCl.	Effectiveness	Mm3	Micro-CT	Random sampling. 1 operator performed the retreatment procedures for all samples. Blinding not specified	Kriskal-Wallis test and additional box-and-whisker plots. (∏<.05)	Although the volume of the filling material decreased significantly in all three groups, none of the systems removed the material completely. Reciproc removed significantly more material than PTU and Reciproc Blue, with the latter two exhibitting equal volume of remaining material.

Table 3: Methodological quality assessment and classification of evidence levels of the selected articles.

Author/Year	Journal/Ranking	Title	Evidence Level
Lu *et al.* 2013 (3)	Int Endod J (Q1)	Apically extruded debris and irrigant with two Ni-Ti systems and hand files when removing root fillings: a laboratory study	A
Rios *et al.* 2014 (7)	J Endod (Q1)	Efficacy of 2 reciprocating systems compared with a rotary retreatment system for gutta-percha removal.	C
Silva *et al.* 2014 (4)	J Endod (Q1)	Reciprocating versus rotary systems for root filling removal: assessment of the apically extruded material	A
Dincer *et al.* 2015 (21)	J Endod (Q1)	Evaluation of apically extruded debris during root canal retreatment with several NiTi systems	A
Akbulut *et al.* 2016 (22)	Dent Mater J (Q2)	Efficacy of Twisted File Adaptive, Reciproc and ProTaper Universal Retreatment instruments for root-canal-filling removal: A cone-beam computed tomography study	D
Crozeta *et al.* 2016 (23)	J Endod (Q1)	Micro-computed tomography study of Filling Material Removal from Oval-shaped Canals by Using Rotary, Reciprocating, and Adaptive Motion Systems	A
Monguilhott Crozeta *et al.* 2016 (24)	Clin Oral Invest (Q1)	A micro-computed tomography assessment of the efficacy of rotary and reciprocating techniques for filling material removal in root canal retreatment	A
Özyürek & Demiryürek 2016 (25)	J Endod (Q1)	Efficacy of different nickel-titanium instruments in removing gutta-percha during root canal retreatment	B
Bago *et a*l. 2019 (26*)*	Int Endod J (Q1)	Comparison of the effectiveness of various rotary and reciprocating systems with different surface treatments to remove gutta-percha and an epoxy resin-based sealer from straight root canals	A

A. Systematic Review/meta-analysis, Evaluation of effectiveness through MicroCT, Myers & Montgomery method for apical debris quantification, Study sample consisting of freshly extracted human teeth, Use of a representative study group, Tooth crown removal to standardize root length, Working length -1 mm from apical foramen, Use of distilled water as irrigant, Post-Hoc statistical analysis if applicable, Bias Control, Double-blind studies.
B. Myers & Montgomery method for apical debris quantification, Samples evaluated through steromicroscope, Sample obtained from human tooth bank, Distilled water as storage medium, Representative sample size, Tooth crown removal to standardize root length, Working length -1 mm from apical foramen, Use of distilled water as irrigant, Post-Hoc statistical analysis if applicable, Bias Control, Double-blind studies.
C. Study samples evaluated through clinical microscope / digital photography, Dry-freezing method for apical debris quantification, Sample consisting of extracted teeth without specifying time since extraction, NaOCl or Thymol as storage mediums, Tooth crown removal to standardize root length, Representative sample size, Working length -1 mm from apical foramen, Irrigation protocol with NaOCl, Post-Hoc statistical analysis if applicable, Bias Control, Blind study design.
D. Study sample evaluated through CBCT, Dry-freezing method for apical debris quantification, Sample consisting of extracted teeth without specifying time since extraction or origin, Storage medium not specified, No representative simple size, No tooth crown removal to standardize root length, Working length -1 mm from apical foramen, Irrigation protocol with NaOCl, No Post-Hoc statistical analysis, Bias Control, Blind study design.

Storage and preservation solutions of tooth samples is a transcendental variable to be taken into account at *in vitro* research, as these solutions are needed to preserve and retain the physical, chemical, and mechanical properties of the stored teeth, and not to alter and/or influence the results of the studies. Among the most used and effective storage solutions are distilled water and chloramine T, since they do not generate changes on enamel or the dentin structure (28).

The studies included in the systemic review have similar purposes and methodologies, evidencing the existence of comparable study groups and similar tooth selection parameters for evaluating the effectiveness, efficiency, and apical extrusion variables. Only studies with straight roots samples were taken into account to increase the probability that such variables (effectiveness, efficiency, and apical extrusion) were analyzed only under the instruments used criteria and were not influenced by root morphology. Inclusion of studies with curved canals would difficult to reach valid conclusions, as they were not performed in similar conditions, following the quality standards guidelines from Faggion, PRISMA, and AMSTAR for selecting studies to be included in a systematic review (8-10).

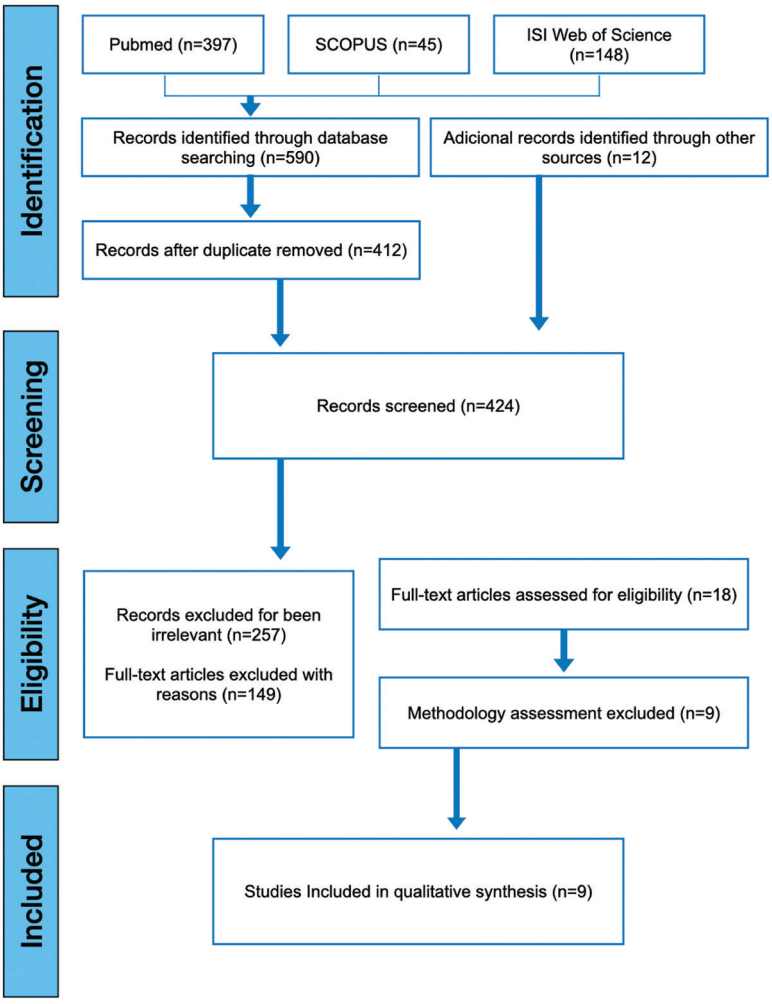

Fig. 1: PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers.

Table 4: Selection Criteria.

Inclusion Criteria	Exclusion Criteria
Systematic reviews and meta-analysis	Narrative reviews concerning endodontic retreatment
In vitro studies performed on natural human teeth	*In vitro* studies using artificial teeth to report the apical extrusion of debris.
Studies evaluating effectiveness, efficiency and/or apical extrusion of filling material, related to the continuous rotation systems (Protaper Universal Retreatment System or Mtwo Retreatment System) and reciprocating systems (Reciproc or WaveOne)	Studies that do not evaluate the effectiveness, efficiency and/or extrusion variables by the aforementioned systems.
Studies comparing at least a rotary system vs a reciprocating system	Studies not establishing a direct comparison between the systems to be evaluated
Studies using gutta-percha as the filling material to be removed	Studies that use endodontic filling materials different to gutta-percha
Studies not using solvent agents during the protocol to remove the filling material	Studies that include solvent agents as part of the protocol to remove the filling material
Studies that evaluate effectiveness through microCT, stereo microscope, dental microscope, digital photographs, SEM and CBCT.	Studies that evaluate effectiveness through radiographs
Studies published in journals ranked Q1 or Q2.	Studies published in journals ranked Q3 or Q4.

Table 5: List of excluded articles after applying methodological evaluation.

Author/Year	Journal	Exclusion criteria
Rödig *et al.* 2014 (12)	Int Endod J	Samples of teeth including curved root canals
De-Deus *et al.* 2015 (13)	Clin Oral Invest	Samples of teeth including mild curved root canals
Bernardes *et al.* 2016 (14)	Int Endod J	Irrigation protocol including ultrasonic activation
Çanakçi *et al.* 2016 (15)	J Endod	Samples of teeth including curved root canals
Alves *et al.* 2016 (16)	J Endod	Samples of teeth including curved root canals
Delai *et al.* 2018 (17)	Braz Dent J	Samples of teeth including curved root canals
Delai *et al.* 2019 (18)	Clin Oral Invest	Samples of teeth including curved root canals
Burbano et al. 2019 (19)	Open Dentistry Journal	Irrigation protocol including ultrasonic activation
Topcuoglu et al. 2020 (20)	Int Endod J	Samples of teeth including simulated apical root resorption.

The working length has also been taken into consideration as it may influence the amount of apically extruded debris. It has been previously shown that a working length of −1 mm from the apical foramen significantly reduces debris extrusion (29), and that, when working on extracted teeth, there is a lack of apical resistance which is naturally provided by the periapical tissues, and therefore, a working length shorter than 1 mm from apical foramen could favor apical debris extrusion (30,31).

Another criterion to consider is the tooth crown sectioning in the selected studies, to standardize the working length and the approximate amount of filling material within the samples, and to rule out the influence of variables such as the crown anatomy and the access to the root canal, thus resulting in more reliable studies (32-34).

The irrigant solutions used during the removing filling material procedure in the selected studies were distilled water (21) and sodium hypochlorite (3,4,7,22-25). The use of distilled water as an irrigant avoids any increase in the weight of the samples, as the formation of sodium hypochlorite crystals has been reported after the evaporation of the extruded liquid (29,35). However, other authors used sodium hypochlorite to make the study similar to clinical conditions (36). In terms of effectiveness and efficiency, the irrigant solutions did not influence variable measurement.

Regarding the inclusion criteria, only studies using gutta-percha as filling material have been selected, as it has been widely demonstrated that besides being the most used root canal filling material, it is ideal to accomplish a three-dimensional seal of the root canal space, preventing bacterial re-infection by blocking the passage of microorganisms and toxins to the periapical tissues. Gutta-percha has been proven to be a highly biocompatible material, with desirable physical and mechanical properties such as dimensional stability and easy insertion and removal from the root canal system (37).

Exclusion criteria were applied to studies using solvent agents during the process of the filling material removal. Although solvent-softened gutta-percha greatly simplifies the removal of filling materials, it may also produce a residual film of softened material along the dentinal walls of the canal, which could affect the procedure´s efficacy (2, 32, 38). Alternatively, chloroform-based solvents are highly cytotoxic when reaching periapical tissues, therefore its use at the root apical third is not recommended (7).

One of the techniques with the highest levels of scientific evidence to quantify the residual filling material is the micro-computed tomography (micro-CT). The micro-CT imaging offers a noninvasive and reproducible high-resolution technique for a 3-dimensional (3D) quantitative evaluation of filling materials (in mm3) before and after instrumentation, allowing a highly accurate calculation of the percentage of residual filling material left inside the root canals after retreatment (12). Longitudinal sectioning of samples before stereomicroscope analysis to evaluate the presence of root canals filling material remnants has also been proposed (39,40). This methodology is effective in measuring remaining filling material when combined using the dental microscope and photographic analysis to obtain clinical images. Nevertheless, the method of sectioning the tooth with stainless steel disks must be performed with high precision to avoid removing the gutta-percha remains, thereby modifying and altering the study samples (41).

Cone-Beam computed tomography (CBCT) is an easily applicable noninvasive clinical tool that provides 3D imaging and quantitative evaluation that could be another eligible method for retreatment evaluation. However, root filling materials are usually radiopaque and may cause artifacts on the CBCT images, although these artifacts can be reduced with proper machine settings and parameters. Smaller voxel sizes and small FOV scans are preferable to minimize the presence of artifacts (22). These artifacts yield discrepancies in the reconstructed images and may lead to misinterpretations affecting the veracity of the study (42). Therefore, CBCT studies were qualified with a lower evidence level method since results are not completely reliable.

This systematic review did not consider studies that evaluate effectiveness through radiographic images, since radiographic images provide only two-dimensional information of a three-dimensional structure, and may be subjected to distortions, which could affect the veracity of the studies (43).

Regarding apical extrusion, the rotary systems still extrude a quantity of material and debris toward the periapical tissues, even though it has been proposed that continuous rotation movement allows the filling material to be dragged coronally (3). Although single-file reciprocating systems are time-efficient at the removal of gutta-percha during endodontic retreatment, it has been shown that they may extrude a greater amount of filling material and debris toward the apex, due to the dynamic of the alternating movement (reciprocating movement), which is a very aggressive movement that removes a large amount of material in a short time, pushing endodontic material and debris toward the apex (41).

Another important inclusion criteria for study selection was the use of the Myers & Montgomery technique or the dry-freezing technique for measuring the amount of extruded filling material. However, the Myers & Montgomery technique has more advantages than the second one as it allows a separate quantification of the amount of extruded material and the quantity of irrigant (44).

Considering the results of the included studies, it is concluded that none of the systems is capable of completely removing the filling material from root canals. This finding is reported in the literature as the impossibility of removing 100% of the total filling material regardless of the applied technique (2,45). However, although the Reciproc and WaveOne systems were not designed specifically for endodontic retreatment, it may be inferred that their special design in conjunction with the reciprocating movement could benefit the material removal, not presenting significant differences regarding effectiveness when compared to Protaper Universal retreatment system (7). In terms of efficiency, there are some different results among the scientific literature that may be related to several variables such as variables inherent to the operator and methods used to calculate the total time required for gutta-percha removal (40).

Conclusions

None of the reviewed systems is effective to completely remove the filling materials from straight root canals, and all systems appear to be equally time-efficient, although this variable shows different results. In terms of apical extrusion, the analyzed reciprocating systems extrude more material toward the periapical tissues than the continuous rotation systems.

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Conflict of interest

None declared.