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Review

Do Continuous Rotating Endodontic Instruments Extrude Fewer Apical Debris Than Reciprocating Instruments in Non-Surgical Endodontic Retreatments? A Systematic Review

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Abstract: Background: All endodontic treatment techniques are associated with the extrusion of debris into periradicular tissues through the apex. The extrusion of apical debris can lead to delayed healing or even therapy failure. It is possible to reduce the extrusion into periapical tissues through various approaches. The objective of this systematic review is to evaluate whether, in cases of non-surgical endodontic retreatment, reciprocating instruments cause greater extrusion of debris compared to instruments with continuous rotation. Methods: A search was conducted on PubMed, Ovid MEDLINE, and the Web of Science. The inclusion criterion was in vitro studies comparing apical extrusion in endodontically treated elements using continuously rotating and reciprocating files. Results: The search on scientific databases yielded 164 results, out of which only 16 were eligible for evaluation after screening. Conclusions: The authors of the research included in this review do not agree on the results obtained. Based on the articles analyzed in this systematic review, it remains unclear whether continuous rotation or reciprocating movement of the endodontic instrument can lead to significant differences in apical debris extrusion; it is not possible to provide a clear clinical recommendation regarding the choice of instrument movement for endodontic procedures.

Keywords: non-surgical endodontic retreatment; root canal preparation; apical debris extrusion; rotary file(s); reciprocating file(s); systematic review

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1. Introduction

Endodontic therapy aims to eliminate bacterial infection from the root canal and maintain the health of the periapical area [1]. Factors such as procedural errors by the operator or tooth-related factors like complex canal anatomy can compromise its outcome [2,3]. Not every endodontic therapy is successful, with success rates ranging from 86% to 96% [4]. In case of endodontic failure, the first therapeutic choice should always be non-surgical endodontic retreatment [5]. However, even this may have a negative outcome, with a success rate of approximately 78% [4,6–8].

Numerous techniques have been proposed to facilitate non-surgical endodontic retreatment, including stainless steel hand files, the use of gutta-percha solvents, ultrasonics,

or NiTi instruments specifically designed for retreatments. Still, none of these techniques guarantees therapy success [9–12].

All endodontic treatment techniques are associated with the extrusion of debris into periradicular tissues through the apex, including necrotic pulp tissue, bacteria, irrigants, or dentinal chips [13–15]. However, in addition to the above factors, the extrusion of root filling materials such as sealer and gutta-percha from the root canal system must be considered in retreatment cases [16–18]. The extrusion of infected debris into periapical tissues leads to inflammation, causing vessel dilation, increased permeability, and the initiation of inflammatory cell chemotaxis [19,20]. A clinical consequence of periradicular inflammation is post-operative pain [21–23]. The intensity of the pain depends on the amount of extruded debris and the virulence of microorganisms [19,24–26]. Furthermore, the extrusion of apical debris can lead to delayed healing or even therapy failure due to a foreign body reaction [1,27]. Although the extrusion of virulent microorganisms into periradicular tissues is recognized as an important causal factor in the development of painful symptoms, even extruded pulp and dentin tissue, though uncontaminated, have the potential to initiate an inflammatory reaction [28–31].

It is possible to reduce the extrusion into periapical tissues through various approaches, such as crown-down instrumentation techniques, which gradually provide access to the canal foramen, abundant phases of canal irrigation, or by choosing the correct file size for maintaining apical patency. Nevertheless, the extrusion of a certain amount of debris remains inevitable during canal instrumentation [19,32–34].

The introduction of instruments with reciprocating motion into the market has brought several advantages compared to instruments with continuous rotation, such as improved resistance to instrument fracture or increased instrument durability [35–40].

However, it is not clear whether this type of movement results in a difference in the amount of extruded debris during the endodontic retreatment procedure.

The objective of this systematic review is to evaluate whether, in cases of non-surgical endodontic retreatment, reciprocating instruments cause greater extrusion of debris compared to instruments with continuous rotation. The hypothesis is that, in cases of non-surgical endodontic retreatment, the use of reciprocating instruments compared to instruments with continuous rotation, does not determine a difference in the quantity of extruded debris.

2. Materials and Methods

2.1. Protocol and Registration

The methods and inclusion criteria of this systematic review were predetermined and documented in a protocol, following the quality standards outlined in the PRISMA 2009 checklist [41]. A detailed protocol outlining the methodology was developed before drafting this paper. The review was registered on the CRD York website, PROSPERO (protocol number, CRD42023415897).

2.2. Search Strategy

The search was conducted in electronic databases, including Ovid MEDLINE, PubMed, and the Web of Science. No manual searches were performed on other databases. For the selection process, the time frame considered was from January 2013 to April 2023.

The following terms and their combinations were used in the search: (apical extrusion) AND (endodontic retreatment). These keywords were chosen to collect and document as much relevant data as possible.

The following focused question was developed in accordance with the Population, Intervention, Comparison, and Outcome (PICO) study design:

"Do continuously rotating endodontic instruments (P) extrude fewer apical debris (O) compared to reciprocating instruments (C) in endodontic retreatments (I)?"

The review included in vitro studies that compared apical extrusion in endodontically treated elements using both continuously rotating and reciprocating files. Only studies

published between January 2013 and April 2023 were considered. The PRISMA flow chart is summarized in Figure 1.

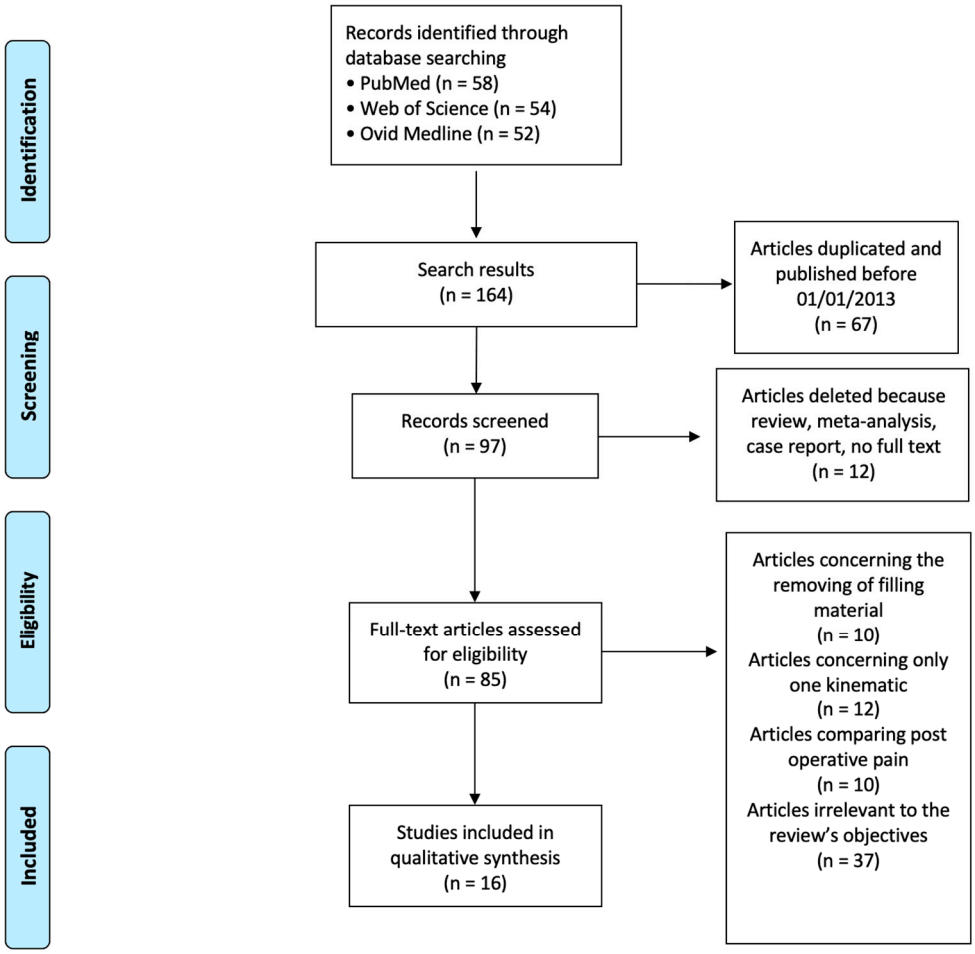

Figure 1. PRISMA flow chart.

2.3. Eligibility Criteria

The full texts of all potentially relevant research papers were assessed, taking into account the following inclusion criteria:

- Articles comparing apical extrusion in endodontically treated elements using continuously rotating and reciprocating files.
- In vitro studies.
- The exclusion criteria considered were as follows:
- Research involving teeth with diseases.
- Research that evaluated apical extrusion using only one type of kinematics.
- Case reports, case series, reviews, and meta-analyses.
- Papers without the full text available.
- Papers not in the English language.

The inclusion and exclusion criteria are summarized in Table 1.

2.4. Risk of Bias Assessment

The risk of bias of the in vitro studies included in this systematic review of the literature was carried out using the CONSORT system [42]. This system is a methodological index composed of a checklist containing 14 questions:

Item 1 analyzes the abstract: The abstract should contain enough information to enable good understanding of the rationale for the approach. The results of the research must be clear in the abstract.

Table 1. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Articles comparing apical extrusion in endodontically treated elements using continuously rotating and reciprocating files.	Research involving teeth with diseases
In vitro studies	Research that evaluated apical extrusion using only one type of kinematics. Case reports, case series, reviews, and meta-analyses. Papers without the full text available. Papers not in the English language

Items 2a and 2b analyze the introduction: Authors should provide clear information about the background and should explain the material or technique to be tested in their experiment. Authors should report similar previously published studies of the topic, and they should explain the rationale for their new project. The objectives of the study and the hypothesis should be reported in the introduction.

Items 3 to 10 analyze the method: It is necessary that other authors can replicate the results by carrying out the same experiment. At these points information on the sample is evaluated:

- If the power analysis was carried out in order to determine the minimum sample number
- If randomization of the division of the sample into groups was carried out
- If the randomization method is explained
- If it is explained who generated the random allocation sequence, who enrolled the patients, and who assigned the patients to intervention
- If it is explained who was blinded after assignment to the intervention
- If the statistical method that will be used to evaluate the results is explained

Item 11 analyzes the results: It is important to report the precision of results as confidence intervals (CI) and the p values.

Item 12 analyzes the discussion section: In this section should be present the advantages and disadvantages of the approach used, a summary of the results obtained, the explanation of why these results were obtained, a comparison with other research, and finally the limitations.

Item 13 and 14 analyzes other information about the research: whether the research has been funded, potential relationships between researchers and sponsors, and finally, where the full trial protocol can be accessed, if available.

3. Results

Two researchers affiliated with Messina University independently conducted an identical literature search. In instances where discrepancies arose in their findings, they sought the input of a third senior researcher at each stage of the process, including initial screening, eligibility assessment for final inclusion, data extraction and analysis, and quality assessment.

Initially, the scientific search engines yielded a total of 164 results. Duplicate studies and those published before 1 January 2013, were excluded, resulting in 97 remaining studies. Among these, 12 articles were excluded because they fell into the categories of reviews, meta-analyses, or case reports. Subsequently, during the initial selection, 85 studies underwent a thorough examination of their full texts. Out of these 85 articles, 10 were omitted as they primarily focused on evaluating the efficacy of files in removing endodontic filling material. An additional 12 were not included because they assessed apical extrusion while comparing only one type of kinematic. Furthermore, 10 were discarded since they

assessed post-operative pain using different kinematics, unrelated to apical debris extrusion. Finally, 37 studies were excluded as they did not align with the objectives of the review. In total, 16 studies were incorporated into this review [43–57]. The included papers are listed in Table 2.

Table 2. Data extraction from selected studies.

Author	File Utilizzato	Evaluation Methods	Object of the Research	Conclusion
T. Koşar 2022 [43]	Genius; ProTaper Next; Reciproc Blue; Tango-Endo; Twisted File Adaptive	pre-weighed Eppendorf tubes.	100 central incisor	No significant differences were found between reciprocant or continuous file.
B Serefoglu 2021 [44]	H-file; R-Endo; Reciproc; ProTaper Retreatment	microbalance	104 severely curved and 104 straight root canals of maxillary molar teeth	No significant differences were found.
C. Solda 2020 [45]	ProTaper retreatment; WaveOne	microbalance	34 mandibular premolar with single root canal	No significant differences were found between the groups
A.A. Azim 2018 [46]	WaveOne Gold; Hyflex EDM; XP Shaper	pre-weighed vials	60 mandibular incisor	No difference was found regarding the amount of extruded debris among the 3 groups
D. Delai 2018 [47]	WaveOne Gold; ProTaper Universal Retreatment; D-RaCe Retreatment; Hand File	pre-weighed Eppendorf tubes.	40 maxillary first molars.	WaveOne Gold produced significantly less debris compared with hand file and D-RaCe Retreatment, and similar to ProTaper Retreatment
G Nevares 2017 [48]	Reciproc; ProTaper Next	pre-weighed Eppendorf tubes.	26 mesial canals of lower molars	No statistical difference
J. H. Li 2017 [49]	hand files; Mtwo Retreatment; Reciproc	microbalance	45 mandibular central incisors	There was no significant difference among 3 groups for debris extrusion
I.Kaşıkçı Bilgi 2017 [50]	H-files; R-Endo; Reciproc; ProTaper Universal Retreatment	microbalance	96 severely curved molars	The reciprocating systems were associated with significantly less extruded debris when compared with H-file; no differences were found between reciprocant instrument and continuous rotation instrument.
K. Yılmaz 2017 [51]	ProTaper Next; Reciproc; Twisted File Adaptive	pre-weighed Eppendorf tubes	90 upper incisor	The RCP file system led to higher levels of apical extrusion in proportion to the PTN file system. Non cè significatività nella quantià di detirti estrusi confrontando Reciproc con Twisted File Adaptive
B.C. Çanakçi 2016 [52]	ProTaper; MTwo; D-Race; R-Endo; Reciproc	pre-weighed Eppendorf tubes.	100 human mandibular premolars with curved root canals	Reciproc produced significantly ($p < 0.001$) more debris than the other systems. ProTaper R and Mtwo R produced significantly ($p < 0.001$) more debris than D-Race and R-Endo.

Table 2. *Cont.*

Author	File Utilizzato	Evaluation Methods	Object of the Research	Conclusion
D. Altunbas 2016 [53]	Reciproc; Twisted File; H-files	pre-weighed Eppendorf tubes.	60 human mandibular premolar	no significant difference was found between the Reciproc and TF systems
E. Uzunoglu 2016 [54]	D-RaCe; EdgeFile XR; Reciproc	pre-weighed Eppendorf tubes.	36 single rooted	Reciproc caused significantly less debris extrusion compared to D-RaCe and EdgeFile XR ($p < 0.05$).
A. N. Dincer 2015 [55]	ProTaper Universal Retreatment; Mtwo; Reciproc; Gates-Glidden burs and H-files	pre-weighed glass vials weighed	60 mandibular incisor	The Reciproc system produced significantly smaller amounts of apical extruded debris than the other groups
E. J. Silva 2015 [56]	ProTaper Retreatment System; WaveOne	visually observed using an operating microscope	40 straight and oval single-rooted premolars	No difference in the amount of debris extruded
E. J. Silva 2014 [57]	ProTaper Universal Retreatment system; Reciproc; WaveOne	Glass vial and microbalance	45 mandibular premolars with a single canal	The ProTaper Universal Retreatment system produced significantly more debris compared with the Reciproc and WaveOne systems

3.1. Risk of Bias

Table 3 presents the risk of bias in the in vitro studies according to CONSORT system.

3.2. Results of Individual Studies

Koşar et al. conducted a study in 2022 where they assessed the quantity of apical debris using pre-weighed Eppendorf tubes. They shaped 100 central incisors with different instruments, including Genius, ProTaper Next, Reciproc Blue, Tango-Endo, and Twisted File Adaptive. Their findings showed no significant differences between the groups using continuous rotation or reciprocating kinematics [43].

In 2021, Serefoglu et al. used a microbalance to measure apical debris obtained with instruments such as H-file, R-Endo, Reciproc, and ProTaper Retreatment. They shaped 104 severely curved and 104 straight root canals of maxillary molar teeth. Their results indicated no significant differences between groups using instruments with continuous rotation and those using reciprocating movement [44].

Solda et al. conducted a study in 2022 using a microbalance to measure the extrusion of apical debris. They shaped root canals with ProTaper Universal Retreatment instruments, followed by refining with the Hero 642 sequence and WaveOne instruments. Their findings showed no significant differences between the groups regarding the amount of material extruded during root canal retreatment [45].

In 2018, Azim et al. measured apical extrusion using pre-weighed vials with 60 mandibular incisors shaped with WaveOne Gold, Hyflex EDM, and XP Shaper. They found no differences in the amount of extruded debris among the three groups [46].

Delai et al. conducted a study in 2018, measuring apical extrusion using pre-weighed Eppendorf tubes with 40 maxillary first molars shaped with WaveOne Gold, ProTaper Universal Retreatment, D-RaCe Retreatment, and Hand File. Their results indicated that WaveOne Gold produced significantly less debris compared to the hand file and D-RaCe Retreatment and was similar to ProTaper Retreatment [47].

Table 3. Risk of bias in the in vitro studies according to CONSORT system.

Item	T. Koşar 2022 [43]	B Serefoglu 2021 [44]	C. Solda 2022 [45]	A.A. Azim 2018 [46]	D. Delai 2018 [47]	G Nevares 2017 [48]	J. H. Li 2017 [49]	I.Kaşıkçı Bilgi 2017 [50]	K. Yılmaz 2017 [51]	B.C. Çanakçi 2016 [52]
1 Abstract	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2a Background and objectives	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2b Background and objectives	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3 Intervention	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4 Outcomes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5 Sample size	No	No	Yes	No	No	No	No	Yes	No	No
6 Randomization: Sequence generation	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes
7 Allocation concealment mechanism	No	No	No	No	Yes	Yes	No	Yes	No	No
8 Implementation	No	No	No	No	Yes	No	No	No	No	No
9 Blinding	Yes	Yes	No	No	Yes	No	No	Yes	No	No
10 Statistical methods	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11 Results, outcomes, and estimation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
12 Discussion Limitations	No	No	No	Yes	Yes	No	No	Yes	No	No
13 Other information Funding	No	No	No	No	No	No	No	No	No	No
14 Protocol	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 3. *Cont.*

Item	D. Altunbas 2016 [53]	E. Uzunoglu 2016 [54]	A. N. Dincer 2015 [55]	E. J. Silva 2015 [56]	E. J. Silva 2014 [57]
1 Abstract	Yes	Yes	Yes	Yes	Yes
2a Background and objectives	Yes	Yes	Yes	Yes	Yes
2b Background and objectives	Yes	Yes	Yes	Yes	Yes
3 Intervention	Yes	Yes	Yes	Yes	Yes
4 Outcomes	Yes	Yes	Yes	Yes	Yes
5 Sample size	No	No	No	No	No
6 Randomization: Sequence generation	Yes	Yes	Yes	Yes	Yes
7 Allocation concealment mechanism	No	No	No	Yes	No
8 Implementation	No	No	No	No	No
9 Blinding	No	No	No	Yes	No
10 Statistical methods	Yes	Yes	Yes	Yes	Yes
11 Results, outcomes, and estimation	Yes	Yes	Yes	Yes	Yes
12 Discussion Limitations	Yes	Yes	Yes	Yes	Yes
13 Other information Funding	No	No	No	No	No
14 Protocol	Yes	Yes	Yes	Yes	Yes

In 2017, Nevares et al. measured apical extrusion using pre-weighed Eppendorf tubes with 26 mesial canals of lower molars shaped with Reciproc or ProTaper Next. They found no statistical differences between the two groups [48].

Li et al. in 2017 used a microbalance to measure the apical extrusion of 45 mandibular central incisors shaped with hand files, Mtwo Retreatment, and Reciproc. They found no significant differences among the three groups in terms of debris extrusion [49].

Kaşıkçı Bilgi conducted a study in 2017 using a microbalance to measure apical extrusion. They used 96 severely curved molars shaped with H-files, R-Endo, Reciproc, and ProTaper Universal Retreatment. The reciprocating systems were associated with significantly less extruded debris compared to H-files, with no differences found between reciprocating instruments and continuous rotation instruments [50].

In 2017, Yılmaz et al. measured apical extrusion using pre-weighed Eppendorf tubes with 90 upper incisors shaped with ProTaper Next, Reciproc, and Twisted File Adaptive. They found no significant differences between the groups with continuous rotation or reciprocating kinematics [51].

Çanakçi et al. in 2016 measured apical extrusion using pre-weighed Eppendorf tubes with 100 mandibular premolars having curved root canals shaped with ProTaper, MTwo, D-Race, R-Endo, and Reciproc. Their results showed that Reciproc produced significantly more debris than the other systems [52].

Altunbas et al. in 2016 measured apical extrusion using pre-weighed Eppendorf tubes with 100 mandibular premolars having curved root canals shaped with ProTaper, MTwo, D-Race, R-Endo, and Reciproc. Similar to the previous study, they found that Reciproc produced significantly more debris than the other systems [53].

Uzunoglu et al. in 2016 measured apical extrusion using pre-weighed Eppendorf tubes with 36 single-rooted teeth shaped with D-RaCe, EdgeFile XR, and Reciproc. Their findings indicated that Reciproc produced significantly less debris extrusion compared to D-RaCe and EdgeFile XR [54].

Dincer et al. in 2015 measured apical extrusion using pre-weighed glass vials with 60 mandibular incisor shaped with ProTaper Universal Retreatment, Mtwo, Reciproc, and Gates-Glidden burs and H-files. They found that the Reciproc system produced significantly smaller amounts of apical extruded debris than the other instruments [55].

Silva et al. in 2015 observed apical extrusion using an operating microscope with 40 straight and oval single-rooted premolars shaped with ProTaper Retreatment System or WaveOne. They found no differences between the two groups [56].

Finally, in 2014, Silva et al. measured apical extrusion using glass vials and a microbalance with 45 mandibular premolars having a single canal shaped with ProTaper Universal Retreatment system, Reciproc, and WaveOne. Their results showed that the ProTaper Universal Retreatment system produced significantly more debris compared to the Reciproc and WaveOne systems [57].

4. Discussion

The effectiveness of reciprocating motion instruments for the removal of filling material during root canal non-surgical retreatment procedures is currently a topic of debate in the literature. Ríos et al. demonstrated that the reciprocating instruments they analyzed are more effective in removing filling materials compared to instruments with continuous rotation [58]. In contrast, other authors concluded that there is no statistically significant difference in the ability to remove canal filling material between reciprocating files and continuous kinematics [59,60]. Some authors have compared the speed of removing endodontic filling materials using reciprocating files or files with continuous rotation. Özyürek et al. found that the continuous rotation instruments they used are significantly faster than the reciprocating system [61]. However, Dincer et al. concluded that there are no significant differences in the time required for the removal of endodontic filling materials between the two types of movements [55].

There is no strong evidence in the literature regarding the use of continuously rotating or reciprocating endodontic instruments to reduce the extrusion of apical debris during endodontic therapy. Recent systematic reviews have examined this issue [40,62]. Pedrinha concluded that the type of motion does not influence the quantity of extruded debris [40]. Ahn, while concluding that reciprocating instruments tended to extrude more dentin debris than continuous rotating instruments, noted that many of the studies included in his review showed conflicting results [62].

This review aims to assess whether there is a correlation between continuous or reciprocating rotation of the endodontic instrument and the extrusion of apical debris in cases of non-surgical endodontic retreatment.

During the phases of canal shaping, dentin, pulp, bacteria, and infected tissues are removed from the root canals. In cases of retreatment, the clinician must not only remove dentin, pulp, and infected tissues but also the main substrate must be removed, which is gutta-percha [19]. This characteristic could potentially lead to a difference in the extrusion of apical debris in cases of endodontic retreatment compared to normal endodontic therapy.

This difference is the reason why the authors decided to write this systematic review of the literature: the systematic reviews of the literature currently published have evaluated apical extrusion during the endodontic therapy and not during the non-surgical endodontic retreatment, in which changes the substrate to be removed from the endodontic system [40,62].

The authors of the research included in this review do not agree on the results obtained [43–57]. Most of them conclude that there are no significant differences in the amount of apical debris extruded using instruments with reciprocating or continuous rotation motion [43–51,53,56]. However, Çanakçi concludes that the analyzed reciprocating instruments extrude a greater amount of debris than instruments with continuous rotation [52]. On the other hand, other authors conclude that reciprocating motion instruments result in less extrusion [47,54,55,57]. There is, therefore, no strong scientific evidence regarding the choice of one of these movements based on the amount of extruded apical debris. The differences in the results obtained from the studies included in this systematic review may be attributed not only to the type of instrument motion used but also to other factors of the endodontic instruments used, such as:

- The different taper [63,64].
- Cross-section, cutting angle, groove depth, radial surfaces, cutting direction [63–65].
- Cutting efficiency [63].
- Thermomechanical treatment [66,67].
- Torque, speed, and taper [68].
- The number of instruments involved in the system.
- The influence of canal curvature [69,70].
- The influence of working length [71,72].
- Influence of apical diameter [73–75].
- Influence of glide path and pre-flaring procedures [15,34,76–78].
- The irrigation protocol [75,79–84].
- Number of files per system [85,86].

The results of these studies cannot definitively determine the primary factor for extruding a larger amount of debris apically, or whether it is the combination of many factors [87]. Apical extrusion is a phenomenon determined by many factors, and from the studies included in this review, it is not possible to identify when the variation in apical extrusion was determined by the type of kinematic of the instrument or by other intervening factors.

Retreatment of a root canal system may be more challenging and time-consuming than the initial treatment [9,88–90]. Because of this, instrument systems have been developed specifically for retreatment procedures, and these instruments are used in continuous rotation [9,72]. It is unclear whether the design of an instrument specifically created for endodontic retreatment may influence the amount of extruded debris.

Some of the studies included in this systematic review have used instruments that the manufacturers declare as "specifically designed for endodontic non-surgical retreatment", such as R-Endo, ProTaper Retreatment, M-Two Retreatment, and D-Race Retreatment, while others have used endodontic instruments not specifically designed for retreatment cases [44,45,47,49,50,52,56,57].

It must also be considered that all the research included in this systematic literature review carries out a quantitative measurement of extruded debris, and not a qualitative evaluation. Further research with a qualitative analysis could lead to greater clarity on how to reduce this phenomenon [91].

Limitation

This study has several limitations that need to be acknowledged. One notable limitation is the absence of periapical resistance simulation, which can be achieved using materials like floral foam and agar gel. In the present study, no such materials were utilized to simulate this resistance. This decision was made due to reported issues with the absorption of foam and the challenge of establishing a definitive value for the thickness of agar gel at the apex to mimic the size of the apical lesion [92,93].

Another limitation is the heterogeneity of the instruments analyzed in the studies included in this systematic review. The authors used a variety of different instruments to assess the quantity of extruded debris, and some even used endodontic instruments specifically designed for retreatments. It is unclear how this heterogeneity may influence the extrusion of apical debris. Despite these limitations, it is important to note that in vitro studies like these have their own set of limitations when extrapolating findings to clinical practice. However, they do allow for addressing internal validity effectively.

Additionally, there is a lack of standardization across the studies. Some authors evaluated incisors, while others assessed premolars or molars, and some focused solely on root portions. This lack of standardization makes direct comparisons difficult and challenges the ability to draw definitive conclusions. To address these limitations and provide more comprehensive insights into the effects of different NiTi alloys on apical transportation, further research is warranted. On a positive note, this article adheres rigorously to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The authors followed a well-defined protocol and conducted a comprehensive literature search, ensuring transparency and reproducibility in the review process. The inclusion of a registered protocol number further enhances the study's credibility. Moreover, the involvement of two independent researchers and consultation with a senior researcher for discrepancies adds to the robustness of the study, increasing the reliability of the findings and strengthening the overall quality of this systematic review.

5. Conclusions

Based on the articles analyzed in this systematic review, it remains unclear whether continuous rotation or reciprocating movement of the endodontic instrument can lead to significant differences in apical debris extrusion. The studies included in this review present conflicting results, and as a result, it is not possible to provide a clear clinical recommendation regarding the choice of instrument movement for endodontic procedures. The authors therefore recommend adopting all those measures useful for removing debris during the treatment, such as glide path and pre-flaring procedures, crown-down instrumentation techniques, constant respect for the working length, abundant phases of canal irrigation, and maintaining apical patency.

To establish a more definitive protocol or recommendation, further studies are required to comprehensively address this issue and provide clearer insights into the impact of instrument movement on apical debris extrusion during endodontic treatments.

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References

1. Ng, Y.L.; Mann, V.; Rahbaran, S.; Lewsey, J.; Gulabivala, K. Outcome of primary root canal treatment: Systematic review of the literature—Part 2. Influence of clinical factors. *Int. Endod. J.* **2008**, *41*, 6–31. [CrossRef]
2. Del Fabbro, M.; Corbella, S.; Sequeira-Byron, P.; Tsesis, I.; Rosen, E.; Lolato, A.; Taschieri, S. Endodontic procedures for retreatment of periapical lesions. *Cochrane Database Syst. Rev.* **2016**, *10*, CD005511. [CrossRef]
3. Estrela, C.; Pécora, J.D.; Estrela, C.R.; Guedes, O.A.; Silva, B.S.; Soares, C.J.; Sousa-Neto, M.D. Common operative procedural errors and clinical factors associated with root canal treatment. *Braz. Dent. J.* **2017**, *28*, 179–190. [CrossRef] [PubMed]
4. Torabinejad, M.; Corr, R.; Handysides, R.; Shabahang, S. Outcomes of nonsurgical retreatment and endodontic surgery: A systematic review. *J. Endod.* **2009**, *35*, 930–937. [CrossRef] [PubMed]
5. Sjogren, U.; Hagglund, B.; Sundqvist, G.; Wing, K. Factors affecting the long-term results of endodontic treatment. *J. Endod.* **1990**, *16*, 498–504. [CrossRef]
6. Stueland, H.; Ørstavik, D.; Handal, T. Treatment outcome of surgical and non-surgical endodontic retreatment of teeth with apical periodontitis. *Int. Endod. J.* **2023**, *56*, 686–696. [CrossRef]
7. Tabassum, S.; Khan, F.R. Failure of endodontic treatment: The usual suspects. *Eur. J. Dent.* **2016**, *10*, 144–147. [CrossRef]
8. Siqueira, J. Aetiology of root canal treatment failure: Why well-treated teeth can fail. *Int. Endod. J.* **2001**, *34*, 1–10. [CrossRef]
9. Di Spirito, F.; Pisano, M.; Caggiano, M.; Bhasin, P.; Lo Giudice, R.; Abdellatif, D. Root Canal Cleaning after Different Irrigation Techniques: An Ex Vivo Analysis. *Medicina* **2022**, *58*, 193. [CrossRef]
10. Takahashi, C.M.; Cunha, R.S.; De Martin, A.S.; Fontana, C.E.; Silveira, C.F.M.; Bueno, C.E.S. In vitro evaluation of the effectiveness of ProTaper Universal rotary retreatment system for gutta-percha removal with or without a solvent. *J. Endod.* **2009**, *35*, 1580–1583. [CrossRef]
11. Giuliani, V.; Cocchetti, R.; Pagavino, G. Efficacy of ProTaper Universal retreatment files in removing filling materials during root canal retreatment. *J. Endod.* **2008**, *34*, 1381–1384. [CrossRef]
12. Ünal, G.C.; Kaya, B.U.; Taç, A.G.; Keçeci, A.D. A comparison of the efficacy of conventional and new retreatment instruments to remove gutta-percha in curved root canals: An ex vivo study. *Int. Endod. J.* **2009**, *42*, 344–350. [CrossRef]
13. Huang, X.; Ling, J.; Wei, X.; Gu, L. Quantitative evaluation of debris extruded apically by using ProTaper Universal Tulsa rotary system in endodontic retreatment. *J. Endod.* **2007**, *33*, 1102–1105. [CrossRef] [PubMed]
14. Prada, I.; Micó-Muñoz, P.; Giner-Lluesma, T.; Micó-Martínez, P.; Collado-Castellano, N.; Manzano-Saiz, A. Influence of microbiology on endodontic failure. Literature review. *Med. Oral Patol. Oral Cir. Bucal* **2019**, *24*, e364–e372. [CrossRef] [PubMed]
15. Tanalp, J.; Güngör, T. Apical extrusion of debris: A literature review of an inherent occurrence during root canal treatment. *Int. Endod. J.* **2014**, *47*, 211–221. [CrossRef] [PubMed]
16. Nair, P. On the causes of persistent apical periodontitis: A review. *Int. Endod. J.* **2006**, *39*, 249–281. [CrossRef] [PubMed]
17. Narayanan, L.L.; Vaishnavi, C. Endodontic microbiology. *J. Conserv. Dent.* **2010**, *13*, 233–239. [CrossRef]
18. Kwang, S.; Abbott, P. The presence and distribution of bacteria in dentinal tubules of root filled teeth. *Int. Endod. J.* **2014**, *47*, 600–610. [CrossRef]
19. Siqueira, J.F., Jr. Microbial causes of endodontic flareups. *Int. Endod. J.* **2003**, *36*, 453–463. [CrossRef]
20. Siqueira, J.F.; Barnett, F. Interappointment pain: Mechanisms, diagnosis and treatment. *Endod. Top.* **2004**, *7*, 93–109. [CrossRef]
21. Di Spirito, F.; Scelza, G.; Fornara, R.; Giordano, F.; Rosa, D.; Amato, A. Post-Operative Endodontic Pain Management: An Overview of Systematic Reviews on Post-Operatively Administered Oral Medications and Integrated Evidence-Based Clinical Recommendations. *Healthcare* **2022**, *10*, 760. [CrossRef]
22. Bürklein, S.; Schäfer, E. Apically extruded debris with reciprocating single-file and full-sequence rotary instrumentation systems. *J. Endod.* **2012**, *38*, 850–852. [CrossRef]
23. Sharma, A.; Sharma, R.; Sharma, M.; Jain, S.; Rai, A.; Gupta, S. Endodontic Flare-ups: An Update. *Cureus* **2023**, *15*, e41438. [CrossRef] [PubMed]
24. Magar, S.S., Sr.; Alfayyadh, A.Y.; Alruwaili, K.K.; Almunahi, H.F.F.; Alsharari, A.H.L.; Magar, S.P. The Determination of Flare-Up Incidence and Associated Risk Factors During Endodontic Treatment: An Observational Retrospective Study. *Cureus* **2022**, *14*, e31424. [CrossRef]
25. Sipavičiūtė, E.; Manelienė, R. Pain and flare-up after endodontic treatment procedures. *Stomatologija* **2014**, *16*, 25–30.
26. Milani, A.S.; Froughreyhani, M.; Taghiloo, H.; Nouroloyouni, A.; Jafarabadi, M.A. The effect of antibiotic use on endodontic post-operative pain and flare-up rate: A systematic review with meta-analysis. *Evid. Based Dent.* **2022**, *11*. [CrossRef] [PubMed]

27. Bassam, S.; El-Ahmar, R.; Salloum, S.; Ayoub, S. Endodontic postoperative flare-up: An update. *Saudi Dent. J.* **2021**, *33*, 386–394. [CrossRef]
28. Seltzer, S.; Soltanoff, W.; Sinai, I. Biologic aspects of endodontics. 3. Periapical tissue reactions to root canal instrumentation. *Oral Surg. Oral Med. Oral Pathol.* **1968**, *26*, 534–546. [CrossRef]
29. Torneck, C.D. Reaction of rat connective tissue to polyethylene tube implants, Part II. *Oral Surg. Oral Med. Oral Pathol.* **1967**, *24*, 674–683. [CrossRef] [PubMed]
30. Naidorf, I.J. Endodontic flare-ups: Bacteriological and immunological mechanisms. *J. Endod.* **1985**, *11*, 462–464. [CrossRef]
31. Torabinejad, M.; Eby, W.C.; Naidorf, I.J. Inflammatory and immunological aspects of the pathogenesis of human periapical lesions. *J. Endod.* **1985**, *11*, 479–488. [CrossRef]
32. Souza, R.A. The importance of apical patency and cleaning of the apical foramen on root canal preparation. *Braz. Dent. J.* **2006**, *17*, 6–9. [CrossRef]
33. Caviedes-Bucheli, J.; Rios-Osorio, N.; Gutiérrez de Pineres-Milazzo, C.; Jiménez-Peña, M.; Portigliatti, R.; Gaviño-Orduña, J.F.; Antúnez-Rivero, M.; Gomez-Sosa, J.F.; Munoz, H.R. Effectiveness, efficiency, and apical extrusion of 2 rotaries and 2 reciprocating systems in removing filling material during endodontic retreatment. A systematic review. *J. Clin. Exp. Dent.* **2023**, *15*, e250–e263. [CrossRef]
34. Gunes, B.; Yeter, K.Y. The effect of cervical preflaring on the apical debris extrusion of single or multiple rotary Ni-Ti files. *Niger. J. Clin. Pract.* **2020**, *23*, 510–514. [CrossRef] [PubMed]
35. Gambarini, G.; Rubini, A.G.; Al Sudani, D.; Gergi, R.; Culla, A.; De Angelis, F.; Di Carlo, S.; Pompa, G.; Osta, N.; Testarelli, L. Influence of different angles of reciprocation on the cyclic fatigue of nickel-titanium endodontic instruments. *J. Endod.* **2012**, *38*, 1408–1411. [CrossRef] [PubMed]
36. De-Deus, G.; Brandão, M.C.; Barino, B.; Di Giorgi, K.; Fidel, R.A.; Luna, A.S. Assessment of apically ex-truded debris produced by the single-file ProTaper F2 technique under reciprocating movement. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod.* **2010**, *110*, 390–394. [CrossRef]
37. Varela-Patiño, P.; Ibañez-Párraga, A.; Rivas-Mundiña, B.; Cantatore, G.; Otero, X.L.; Martin-Biedma, B. Alternating versus continuous rotation: A comparative study of the effect on instrument life. *J. Endod.* **2010**, *36*, 157–159. [CrossRef]
38. Ferreira, F.; Adeodato, C.; Barbosa, I.; Aboud, L.; Scelza, P.; Zaccaro Scelza, M. Movement kinematics and cyclic fatigue of NiTi rotary instruments: A systematic review. *Int. Endod. J.* **2017**, *50*, 143–152. [CrossRef]
39. De Almeida-Gomes, F.; de Matos, H.R.; Nunes, R.F.; Arrais, A.M.; Ferreira-Maniglia, C.; de Morais Vitoriano, M.; Gurgel-Filho, E.D. Cyclic fatigue resistance of different continuous rotation and reciprocating endodontic systems. *Indian J. Dent. Res.* **2016**, *27*, 278–282. [CrossRef] [PubMed]
40. Pedrinha, V.F.; Brandão, J.M.D.S.; Pessoa, O.F.; Rodrigues, P.A. Influence of File Motion on Shaping, Apical Debris Extrusion and Dentinal Defects: A Critical Review. *Open Dent. J.* **2018**, *12*, 189–201. [CrossRef] [PubMed]
41. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med.* **2009**, *6*, e1000097. [CrossRef]
42. Faggion, C.M. Guidelines for Reporting Pre-clinical In Vitro Studies on Dental Materials. *J. Évid. Based Dent. Pract.* **2012**, *12*, 182–189. [CrossRef]
43. Koşar, T.; Çelik, D.; Taşdemir, T. Apically extruded debris of different file systems used with various kinematic movements during retreatment: An in vitro study. *Aust. Endod. J.* **2022**, *49*, 33–40. [CrossRef]
44. Serefoglu, B.; Kandemir Demirci, G.; Miçooğulları Kurt, S.; Kaşıkçı Bilgi, İ.; Çalışkan, M.K. Impact of root canal curvature and instrument type on the amount of extruded debris during retreatment. *Restor. Dent. Endod.* **2020**, *46*, e5. [CrossRef]
45. Solda, C.; Padoim, K.; Rigo, L.; Silva Sousa, Y.T.C.; Hartmann, M.S.M. Assessment of Apical Extrusion using Rotary and Reciprocating Systems during Root Canal Retreatment. *J. Contemp. Dent. Pract.* **2020**, *21*, 238–241. [CrossRef]
46. Azim, A.A.; Wang, H.H.; Tarrosh, M.; Azim, K.A.; Piasecki, L. Comparison between Single-file Rotary Systems: Part 1—Efficiency, Effectiveness, and Adverse Effects in Endodontic Retreatment. *J. Endod.* **2018**, *44*, 1720–1724. [CrossRef]
47. Delai, D.; Boijink, D.; Hoppe, C.B.; Grecca, A.S.; Kopper, P.M.P. Apically extruded debris in filling removal of curved canals using 3 NiTi systems and hand files. *Braz. Dent. J.* **2018**, *29*, 54–59. [CrossRef]
48. Nevares, G.; Romeiro, K.; Albuquerque, D.; Xavier, F.; Fogel, H.; Freire, L.; Cunha, R. Evaluation of Apically Extruded Debris during Root Canal Retreatment Using ProTaper Next and Reciproc in Severely Curved Canals. *Iran. Endod. J.* **2017**, *12*, 323–328.
49. Li, J.H.; Wu, T.T.; He, H.; Han, J.L. Evaluation of the efficacy of two kinds of NiTi retreatment instruments for removing filling material during root canal retreatment. *Shanghai Kou Qiang Yi Xue* **2017**, *26*, 268–271. (In Chinese)
50. Kaşıkçı Bilgi, I.; Köseler, I.; Güneri, P.; Hülsmann, M.; Çalışkan, M.K. Efficiency and apical extrusion of debris: A comparative ex vivo study of four retreatment techniques in severely curved root canals. *Int. Endod. J.* **2017**, *50*, 910–918. [CrossRef] [PubMed]
51. Yılmaz, K.; Özyürek, T. Apically Extruded Debris after Retreatment Procedure with Reciproc, ProTaper Next, and Twisted File Adaptive Instruments. *J. Endod.* **2017**, *43*, 648–651. [CrossRef]
52. Çanakçi, B.C.; Ustun, Y.; Er, O.; Genc Sen, O. Evaluation of Apically Extruded Debris from Curved Root Canal Filling Removal Using 5 Nickel-Titanium Systems. *J. Endod.* **2016**, *42*, 1101–1104. [CrossRef]
53. Altunbas, D.; Kutuk, B.; Toyoglu, M.; Kutlu, G.; Kustarci, A.; Er, K. Reciproc versus Twisted file for root canal filling removal: Assessment of apically extruded debris. *J. Istanb. Univ. Fac. Dent.* **2016**, *50*, 31–37. [CrossRef]

54. Uzunoglu, E.; Turker, S.A. Impact of different file systems on the amount of apically extruded debris during endodontic retreatment. *Eur. J. Dent.* **2016**, *10*, 210–214. [CrossRef]
55. Dincer, A.N.; Er, O.; Canakci, B.C. Evaluation of apically extruded debris during root canal retreatment with several NiTi systems. *Int. Endod. J.* **2015**, *48*, 1194–1198. [CrossRef] [PubMed]
56. Silva, E.J.; Orlowsky, N.B.; Herrera, D.R.; Machado, R.; Krebs, R.L.; de Souza Coutinho-Filho, T. Effectiveness of rotatory and reciprocating movements in root canal filling material removal. *Braz. Oral Res.* **2015**, *29*, 1–6. [CrossRef]
57. Leal Silva, E.J.N.; Sa, L.; Belladonna, F.G.; Neves, A.A.; Accorsi-Mendonça, T.; Vieira, V.T.; De-Deus, G.; Moreira, E.J. Reciprocating versus rotary systems for root filling removal: Assessment of the apically extruded material. *J. Endod.* **2014**, *40*, 2077–2080. [CrossRef]
58. Rios, M.A.; Villela, A.M.; Cunha, R.S.; Velasco, R.C.; De Martin, A.S.; Kato, A.S. Efficacy of 2 reciprocating systems compared with a rotary retreatment system for gutta-percha removal. *J. Endod.* **2014**, *40*, 543–546. [CrossRef]
59. Akbulut, M.B.; Akman, M.; Terlemez, A.; Magat, G.; Sener, S. Efficacy of Twisted File Adaptive, Reciproc and ProTaper Universal Retreatment instruments for root canal filling removal: A cone-beam computed tomography study. *Dent. Mater. J.* **2016**, *35*, 126–131. [CrossRef]
60. Monguilhott Crozeta, B.; de Souza-Neto, M.D.; Bianchi Leoni, G.; Mazzi-Chavez, J.F.; Correa Silva-Sousa, Y.T.; Baratto-Filho, F. A micro-computed tomography assessment of the efficacy of rotary and reciprocating techniques for filling material removal in root canal retreatment. *Clin. Oral Investig.* **2016**, *20*, 2235–2240. [CrossRef]
61. Özyürek, T.; Demiryürek, E.O. Efficacy of different nickel-titanium instruments in removing gutta-percha during root canal retreatment. *J. Endod.* **2016**, *42*, 646–649. [CrossRef] [PubMed]
62. Ahn, S.Y.; Kim, H.C.; Kim, E. Kinematic Effects of Nickel-Titanium Instruments with Reciprocating or Continuous Rotation Motion: A Systematic Review of In Vitro Studies. *J. Endod.* **2016**, *42*, 1009–1017. [CrossRef]
63. Nevares, G.; Xavier, F.; Gominho, L.; Cavalcanti, F.; Cassimiro, M.; Romeiro, K.; Alvares, P.; Queiroz, G.; Sobral, A.P.; Gerbi, M.; et al. Apical extrusion of debris produced during continuous rotating and reciprocating motion. *Sci. World J.* **2015**, *2015*, 267264. [CrossRef]
64. Surakanti, J.R.; Venkata, R.C.; Vemisetty, H.K.; Dandolu, R.K.; Jaya, N.K.; Thota, S. Comparative evaluation of apically extruded debris during root canal preparation using ProTaper™, Hyflex™ and Waveone™ rotary systems. *J. Conserv. Dent.* **2014**, *17*, 129–132. [CrossRef]
65. Roda-Casanova, V.; Pérez-González, A.; Zubizarreta-Macho, A.; Faus-Matoses, V. Influence of Cross-Section and Pitch on the Mechanical Response of NiTi Endodontic Files under Bending and Torsional Conditions—A Finite Element Analysis. *J. Clin. Med.* **2022**, *11*, 2642. [CrossRef]
66. Karataş, E.; Ersoy, İ.; Gündüz, H.A.; Uygun, A.D.; Kol, E.; Çakıcı, F. Influence of instruments used in root canal preparation on amount of apically extruded debris. *Artif. Organs* **2016**, *40*, 774–777. [CrossRef]
67. Puleio, F.; Bellezza, U.; Torre, A.; Giordano, F.; Lo Giudice, G. Apical Transportation of Apical Foramen by Different NiTi Alloy Systems: A Systematic Review. *Appl. Sci.* **2023**, *13*, 10555. [CrossRef]
68. Puleio, F.; Lo Giudice, G.; Militi, A.; Bellezza, U.; Lo Giudice, R. Does Low-Taper Root Canal Shaping Decrease the Risk of Root Fracture? A Systematic Review. *Dent. J.* **2022**, *10*, 94. [CrossRef]
69. Borges, M.F.; Miranda, C.E.; Silva, S.R.; Marchesan, M. Influence of apical enlargement in cleaning and extrusion in canals with mild and moderate curvatures. *Braz. Dent. J.* **2011**, *22*, 212–217. [CrossRef]
70. Aydin, U.; Zer, Y.; Zorlu Golge, M.; Kirkgoz Karabulut, E.; Culha, E.; Karataslioglu, E. Apical extrusion of Enterococcus faecalis in different canal geometries during the use of nickel titanium systems with different motion types. *J. Dent. Sci.* **2017**, *12*, 1–6. [CrossRef] [PubMed]
71. Teixeira, J.M.; Cunha, F.M.; Jesus, R.O.; Silva, E.J.; Fidel, S.R.; Sassone, L.M. Influence of working length and apical preparation size on apical bacterial extrusion during reciprocating instrumentation. *Int. Endod. J.* **2015**, *48*, 648–653. [CrossRef] [PubMed]
72. De Moura, J.D.M.; Bueno, C.E.; Fontana, C.E.; Pelegrine, R.A. Extrusion of debris from curved root canals instrumented up to different working lengths using different reciprocating systems. *J. Endod.* **2019**, *45*, 930–934. [CrossRef] [PubMed]
73. Chang, J.W.; Cheung, A.W.; Cheung, G.S. Effect of root canal dimensions, injection rate, and needle design on the apical extrusion of an irrigant: An in vitro study. *J. Investig. Clin. Dent.* **2015**, *6*, 221–227. [CrossRef] [PubMed]
74. Silva, E.J.; Teixeira, J.M.; Kudsi, N.; Sassone, L.M.; Krebs, R.L.; Coutinho-Filho, T.S. Influence of apical preparation size and working length on debris extrusion. *Braz. Dent. J.* **2016**, *27*, 28–31. [CrossRef]
75. Cuellar, M.R.; Velásquez-Espedilla, E.G.; Pedrinha, V.F.; Vivan, R.R.; Duarte, M.A.; Andrade, F.B. Can kinematics, file diameter, and PUI influence the intracanal decontamination and apical bacterial extrusion? *Braz. Oral Res.* **2020**, *35*, e003. [CrossRef]
76. Keskin, C.; Sivas Yilmaz, Ö.; Inan, U. Apically extruded debris produced during glide path preparation using R-Pilot, WaveOne Gold Glider and ProGlider in curved root canals. *Aust. Endod. J.* **2020**, *46*, 439–444. [CrossRef]
77. Plotino, G.; Nagendrababu, V.; Bukiet, F.; Grande, N.M.; Veettil, S.K.; De-Deus, G.; Aly Ahmed, H.M. Influence of Negotiation, Glide Path, and Preflaring Procedures on Root Canal Shaping-Terminology, Basic Concepts, and a Systematic Review. *J. Endod.* **2020**, *46*, 707–729. [CrossRef]
78. Topçuoğlu, H.S.; Üstün, Y.; Akpek, F.; Aktı, A.; Topçuoğlu, G. Effect of coronal flaring on apical extrusion of debris during root canal instrumentation using single-file systems. *Int. Endod. J.* **2016**, *49*, 884–889. [CrossRef]

79. Barbosa-Ribeiro, M.; Arruda-Vasconcelos, R.; Fabretti, F.L.; Silva, E.J.; De-Deus, G.; Gomes, B.P. Evaluation of apically extruded debris using positive and negative pressure irrigation systems in association with different irrigants. *Braz. Dent. J.* **2018**, *29*, 184–188. [CrossRef]
80. Psimma, Z.; Boutsioukis, C.; Kastrinakis, E.; Vasiliadis, L. Effect of needle insertion depth and root canal curvature on irrigant extrusion ex vivo. *J. Endod.* **2013**, *39*, 521–524. [CrossRef]
81. Yeter, K.Y.; Evcil, M.S.; Ayranci, L.B.; Ersoy, I. Weight of apically extruded debris following use of two canal instrumentation techniques and two designs of irrigation needles. *Int. Endod. J.* **2013**, *46*, 795–799. [CrossRef]
82. Azim, A.A.; Aksel, H.; Jefferson, M.M.; Huang, G.T. Comparison of sodium hypochlorite extrusion by five irrigation systems using an artificial root socket model and a quantitative chemical method. *Clin. Oral Investig.* **2018**, *22*, 1055–1061. [CrossRef]
83. Kirchhoff, A.L.; Fariniuk, L.F.; Mello, I. Apical extrusion of debris in flat-oval root canals after using different instrumentation systems. *J. Endod.* **2015**, *41*, 237–241. [CrossRef]
84. Shah, T.; Ramesh, S.; Sugumaran, S.; Choudhari, S. Endodontic retreatment efficacy with and without solvents: A systematic review. *J. Conserv. Dent. Endod.* **2023**, *26*, 610–615.
85. Caviedes-Bucheli, J.; Castellanos, F.; Vasquez, N.; Ulate, E.; Munoz, H.R. The influence of two reciprocating single-file and two rotary-file systems on the apical extrusion of debris and its biological relationship with symptomatic apical periodontitis. A systematic review and meta-analysis. *Int. Endod. J.* **2016**, *49*, 255–270. [CrossRef]
86. Sun, C.; Sun, J.; Tan, M.; Hu, B.; Gao, X.; Song, J. Pain after root canal treatment with different instruments: A systematic review and meta-analysis. *Oral Dis.* **2018**, *24*, 908–919. [CrossRef]
87. Duncan, H.F.; Chong, B.S. Removal of root filling materials. *Endod. Top.* **2008**, *19*, 33–57. [CrossRef]
88. Di Lauro, A.E.; Valletta, A.; Aliberti, A.; Cangiano, M.; Dolce, P.; Sammartino, G.; Gasparro, R. The Effectiveness of Autologous Platelet Concentrates in the Clinical and Radiographic Healing after Endodontic Surgery: A Systematic Review. *Materials* **2023**, *16*, 7187. [CrossRef] [PubMed]
89. Iandolo, A.; Abdellatif, D.; Barbosa, A.F.A.; Scelza, G.; Gasparro, R.; Sammartino, P.; Silva, E.J.N.L. Confocal laser scanning microscopy evaluation of roots subjected to activation protocol in endodontic microsurgery. *Aust. Endod. J.* **2022**, *48*, 77–81. [CrossRef]
90. Boutsioukis, C.; Arias-Moliz, M.T.; de Paz, L.E.C. A critical analysis of research methods and experimental models to study irrigants and irrigation systems. *Int. Endod. J.* **2022**, *55*, 295–329. [CrossRef]
91. Laslami, K.; Khaldoune, S.; Sy, A.; Drouri, S.; Benkiran, I. Apical Extrusion: Is It an Inherent Occurrence during Every Endodontic Treatment? *Cureus* **2023**, *15*, e45211. [CrossRef]
92. Altundasar, E.; Nagas, E.; Uyanik, O.; Serper, A. Debris and irrigant extrusion potential of 2 rotary systems and irrigation needles. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod.* **2011**, *112*, 31–35. [CrossRef] [PubMed]
93. Lu, Y.; Wang, R.; Zhang, L.; Li, H.L.; Zheng, Q.H.; Zhou, X.D.; Huang, D.M. Apically extruded debris and irrigant with two NiTi systems and hand files when removing root fillings: A laboratory study. *Int. Endod. J.* **2013**, *46*, 1125–1130. [CrossRef] [PubMed]