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Guided Endodontics for Non-surgical Root Canal Retreatment: A Systematic Review

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Introduction: This systematic review compared the accuracy of guided endodontics with the conventional method in non-surgical endodontic retreatment. **Methods:** Two reviewers conducted a systematic search across PubMed/MEDLINE, Scopus, Embase, and Web of Science databases. Inclusion criteria consisted of all *in vitro* studies up to October 2024 that documented the application of cone-beam computed tomography in creating a guide for endodontic retreatment cases. The reviewers assessed the quality of the selected studies using the QUIN tool. Data regarding the first author and publication year, sample size, tooth type, retreatment application, computer-aided navigation technique, groups, image acquisition method, outcome measures, guided technique results, conventional technique results, and the main results were extracted using a predefined template. **Results:** Based on our criteria, seven studies were included in this review. The studies demonstrated variability in the techniques utilized. Iatrogenic errors were less frequent in guided groups, regardless of the operator's level of experience. Most studies indicated that guided endodontics was more effective than conventional methods, particularly in fiber post-removal and access through MTA, minimizing volumetric loss of tooth structure, and preserving fracture resistance. However, when using guided techniques for removal of separated instruments, more iatrogenic errors occurred, and more time was required compared to the freehand technique. **Conclusion:** Guided endodontics has shown promise in improving the outcomes of non-surgical retreatment by reducing complications. However, as all included studies were *in vitro*, clinical evidence is lacking, and the generalization of these results should be done cautiously. Further well-designed clinical studies are required to confirm these findings.

Keywords: Guided Endodontics; Guided Technique; Retreatment; Root Canal Treatment; Systematic Review

Introduction

Microorganisms can persist or recolonize within the root canal system after endodontic treatment. Common causes of failure include inadequate mechanical debridement, bacterial persistence in the canals and apex, poor quality of obturation, overfilling or underfilling of the root canal, and coronal leakage. To minimize the presence of microorganisms, it is essential to remove as much obturating material (gutta-percha and root canal sealer) as possible from the root canal system [1, 2]. In most cases, retreatment of a failed root canal therapy using an orthograde approach is feasible. Non-surgical retreatment should always be the primary approach for failed primary endodontic treatments. On the other hand, surgical retreatment would be the last alternative to save a tooth [3]. Nonetheless, the involvement or loss of dentin throughout retreatment procedures can potentially induce dentinal defects, which may compromise the fracture resistance of the tooth and precipitate vertical root fractures (VRFs) under occlusal stresses [4].

In clinical practice, repeated endodontic procedures are often required to treat teeth with various complications and root canal blockages, including obliteration of canals, instrument fragments, or the presence of retention approaches in the root canal [5]. Removing intraradicular blockages, such as posts, separated endodontic instruments, or mineral trioxide aggregate

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(MTA) to reach the apex is important to optimize sterilization before sealing the root canal space [6, 7]. In order to retrieve instruments or posts from the root canal, various tools and procedures are used, including various ultrasonic armamentaria, extractors, and special kits [8-10].

Guided endodontics, a recent approach, has been indicated for better management of teeth with challenging endodontic treatment [11]. Recently, it has gained popularity as a technique for root canal localization and preparation in calcified root canals, furcation perforations, dental anomalies such as dens invaginatus, dentin dysplasia, and dentinogenesis imperfecta as well as for the removal of root canal barriers like glass fiber posts, MTA, and in microsurgical endodontic procedures [12-24]. An *in vitro* study by Perez *et al.* [25] on fiber post removal in natural teeth using guided endodontics showed high accuracy between the digital plan and the actual clinical procedure. There are two main types of guided approaches in endodontics: static navigation (SN), and dynamic navigation system (DNS). Static guidance uses a fixed stent created through computer-aided design/computer-assisted manufacture (CAD/CAM) based on data from a preoperative cone-beam computed tomography (CBCT) scan. Those data along with 3-dimensional (3D) digital impression scanning allows virtual planning of the canal access cavity. These guides can be supported by teeth, mucosa, or bone [27 ,26]. This method has been identified as a highly effective approach for achieving an optimal clinical outcome, offering benefits such as high accuracy and speed while enhancing the preservation of tooth structure and minimizing the risk of iatrogenic damages [28-30]. There are also significant drawbacks to its use. The guides' fixed angulation, size, and depth are not easily adjustable. Additionally, production costs and the time required for planning and manufacturing static guides can be challenging. Additionally, static guides may not be suitable for patients with restricted mouth opening or in the second molar regions where access is limited. In general, although the guided endodontics can increase the time and cost of planning, it provides more reliability to the clinician in calcified teeth, decreases the chair time, and improves the treatment outcomes [21, 31, 32].

The dynamic approach combines handpieces and radiographic images using an optical positioning device managed via a specialized computer interface. It employs a stereoscopic monitoring camera to offer real-time guidance, ensuring the operator's instruments are directed to the correct location for procedures such as root canal localization, root-end resection, implant placement, *etc.* [33, 34]. Dynamic navigation systems offer several advantages, including a flexible treatment plan that can be modified at any stage of the procedure, improved accuracy, and reduced risk to critical structures. However, they also have drawbacks, including longer procedure times, extra procedural steps and learning curve, potential iatrogenic errors due to software processing delays, and the need for accurate hand-eye coordination [31].

Performing orthograde root canal retreatment on teeth with intraradicular blockages, such as teeth with fiber posts or separated instruments, presents a significant challenge for general dental practitioners. Attempting to remove them manually can be very time-consuming and may lead to iatrogenic errors, such as perforations or excessive loss of dentin [35, 36].

Literature reveals several case reports, case series, *in vitro*, *ex vivo,* and review studies, which have highlighted the overall application of guided navigation systems in endodontic retreatment in complicated cases. A systematic review by Poirazi *et al.* concluded that guided endodontics is efficient for removing dental posts, with minimal risk of iatrogenic errors [37].

There is no review of present studies to evaluate the accuracy of two guidance methods in endodontic retreatments. This systematic review aims to compare SN/DNS with conventional techniques (FH) in non-surgical retreatment of endodontic cases.

Materials and Methods

Protocol

This systematic review was conducted in accordance with the standards set by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [38].

PICO Question

The present study question was based on the PICO question "Comparative evaluation of guided endodontics to conventional technique (freehand (FH)) in the retreatment of endodontically treated teeth. "

- Population: Endodontically treated teeth used in *in vitro* studies
- Intervention: guided endodontics (DNS or SN)
- Comparator: conventional freehand technique (FH)
- Outcome: Accuracy (measured as coronal and apical deviations, angular deviations, and procedural errors), volumetric loss of tooth structure, iatrogenic errors (*e.g.*, perforations and deviations), and time efficiency

Eligibility criteria

All *in vitro* studies published up to October 2024 that reported the use of CBCT as guidance for root canal retreatment (including dental post removal, retrieval of separated

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instruments, and identification of missed canals), were considered eligible for inclusion. Case reports, case series, clinical trials, poster presentations, abstracts, literature reviews, letters to the editor, techniques, expert opinions, and studies not published in English were excluded.

Search strategy

The approach for this systematic review followed the PRISMA guidelines. Two independent reviewers (STA and PS) conducted a comprehensive search across four databases PubMed, Scopus, Web of Science, and Embase for publications up to October 2024. Table 1 lists the search keywords and the number of articles retrieved from each database.

Study selection

The two reviewers independently removed duplicates and evaluated the articles in two stages: first, by reviewing titles and abstracts, and second, by analyzing the full text. Articles with limited information in their title and abstract were included in the second stage for full-text evaluation to ensure no relevant publications were excluded. Any disagreements were resolved through discussion.

Data extraction

The two reviewers independently extracted the data from the studies using a predetermined template. The extracted information included details such as first author and year, sample size, tooth type, retreatment application, computer-aided navigation technique, groups, image acquisition method, outcome measures, guided technique results, conventional technique results, and main result. Any disagreements were resolved through discussion.

Quality assessment

The Quality Assessment Tool for "*In Vitro* Studies" (QUIN Tool) was used to evaluate the quality of the included studies [39]. This tool evaluates twelve criteria, including: clearly defined aims or objectives, detailed explanation of sample size calculation, description of the sampling technique, information on comparison groups, comprehensive methodology details, operator details, randomization process, method of outcome measurement, and information on outcome assessors, blinding, statistical analysis, and presentation of results. Each criterion is scored as follows: 2 for adequately specified, 1 for not adequately specified, 0 for not specified, and NA if not applicable. The scores for all criteria are summed to calculate the final score for each study. This score is then used to classify studies into three categories of bias risk: low risk (>70%), medium risk (50–70%), and high risk (<50%), using the formula: Final score=(Total score×100)/(2×number of criteria applicable) [40]. Due to the variation in the data across the included articles, a quantitative meta-analysis was not feasible.

Results

Search results

The search strategy used in this systematic review, in accordance with the PRISMA guidelines, is illustrated in Figure 1. Furthermore, Table 1 shows the number of articles gathered from each database. Eighty-five articles were initially obtained from four search engines. After removing duplicates, 45 articles were screened based on their titles and abstracts. Of these, 32 articles were selected for full-text retrieval. Upon full-text evaluation, only 7 articles met the inclusion criteria. Twenty-five studies were excluded for not meeting the predetermined inclusion criteria for this systematic review. Seventeen articles were excluded because they were case reports. Two review articles, a technique, and a book chapter were also excluded. Three *in vitro* articles were also excluded because they did not have a comparative FH group in their studies. Table 2 provides a summary of the characteristics of the included studies.

Study characteristics

Among the seven studies included in this review, two utilized DNS as their guided approach[42 ,41] , while five employed SN as their guided method [17, 43-46]. All the studies included the assessment of image acquisition using CBCT [17, 41-43, 45, 46], except for one study that used a micro-CT scanner [44]. One study evaluated the fracture resistance of teeth, showing that the SN group significantly maintained fracture resistance compared to the control group [17].

Main results

Fiber post removal

The guided approach was found to be highly effective for fiber post removal, with four studies reporting that it required less time compared to the FH technique. Additionally, the guided approach minimized volumetric loss of tooth structure and enhanced accuracy [41, 43-45].

File removal

One study analyzed removal of separated instrument using DNS compared to FH technique under the dental operating microscope, and reported that the guided approach resulted in more iatrogenic errors and time consumed [42].

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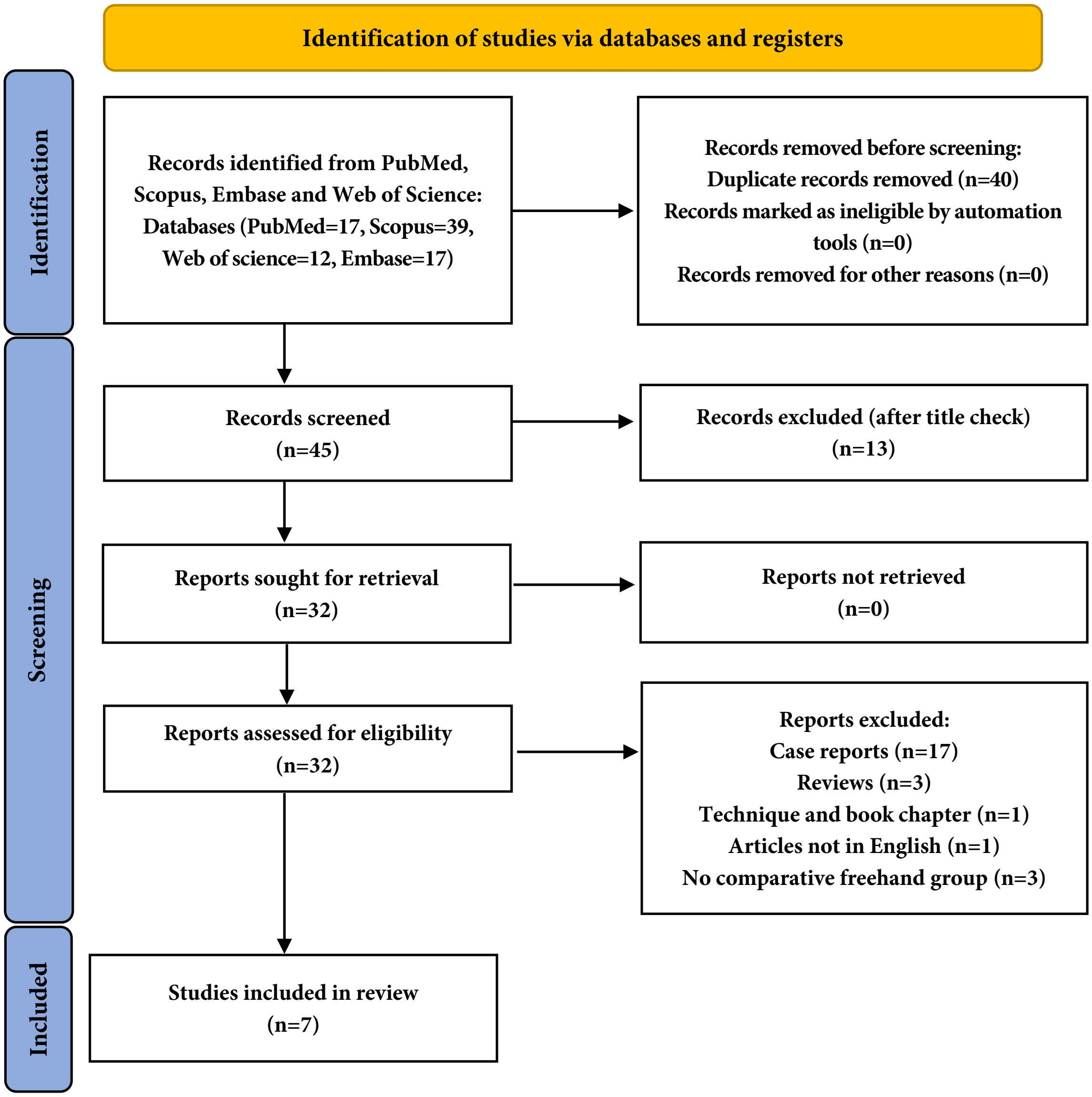

Figure 1. Flowchart of the selection process

Tooth substance loss

Five studies assessed the volume of tooth substance loss caused by guided and conventional methods [41-44, 46]. The guided approach significantly reduced the volumetric loss of tooth structure in most cases, except for one study where greater tooth volume loss was reported in the guided group, while removing intracanal separated instrument [42].

Iatrogenic errors

Four studies evaluated deviations [41, 43-45], and five studies measured perforations [17, 41-44]. None of the perforations were observed in guided groups except for one case, where a single perforation occurred in the guided group [43]. In general, iatrogenic errors were found to be less frequent in guided groups, regardless of the operator's level of experience.

Risk of bias evaluation

Table 3 provides a comprehensive summary of the bias risk evaluation using the QUIN tool. For the *in vitro* studies, one study was deemed as high risk [46], three as low risk [17, 41, 43], and three as medium risk [42, 44, 45]. None of the studies with more than one operator indicated any blinding of the operators [43, 44]. All *in vitro* studies clearly outlined their objectives and provided a detailed description of the sampling technique. None of the included studies disclosed any conflicts of interest.

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Table 1. Search keywords and the number of articles retrieved from each database

Keywords	PubMed	Scopus	Web of Science	Embase
(“dynamic navigation system” or “dynamic guided endodontics” or “real-time guided endodontics” or “RTGE” or “DNS” or “dynamic navigation” or “computer-aided” or “computer-aided navigation” or “computer-assisted treatment” or “guided endodontic” or “dynamic guide” or “navigation system” or “static navigation” or “static guidance” or “static guided endodontics” or “printed template” or “guided technique”)[a] AND (“dental post removal” or “fiber post removal” or “broken instrument retrieval” or “broken endodontic file retrieval” or “separated instrument retrieval” or “MTA” or “broken file removal” or “endodontic retreatment” or “root canal retreatment”)[a]	17	39	12	17

[a] *PubMed, Scopus, Web of Science, and Embase*

Table 2. Extracted data from the included studies

Study	Sample size	Tooth type	RA	CNT	Groups	IAM	Outcome (GT) *vs.* (CT)	Main result
Janabi *et al.* [41]	26 (*n*=13)	maxillary canines and incisors	Fiber post removal	DNS (X-guide SYSTEM)	G 1: DNS G 2: FH	CBCT (0.120-mm^3 voxel size resolution)	Global coronal deviation (0.91±0.65 mm) *vs* (1.13±0.84 mm) Global apical deviation (1.17±0.64 mm) *vs* (1.68±0.85 mm) Angular deflection (1.75°±0.63°) *vs* (4.49°±2.10°) Operation time (4.03±0.43 min) *vs* (8.30±4.65 min) Volume of tooth structure (Before=542.50±81.97 mm^3 After=487.87±74.70 mm^3) *vs* (Before=571.34±132.05 mm^3 After=533.16±133.12 mm^3)	The DNS method demonstrated greater accuracy and efficiency in removing fiber posts from endodontically treated teeth when compared to the FH method
Ali *et al.* [17]	30 (*n*=15)	single root canal mandibular premolars	accessing the root canal through MTA	SN	G 1: Control G 2: Static-guided (SN)	CBCT (constant thickness 0.65 mm per slice, 84 kV, 6.0 mA, 12 sec)	Mishaps (*n*=0) *vs* (*n*=13) Time to penetration to the root canal (shorter penetration time *(not specified by number)* *vs* (longer penetration time *(not specified by number)*) Fracture strengths (1379.8 Newtons) *vs* (472.3 Newtons) **4.** Failure type (Failure type (Restorable *n*=12/ Non Restorable=3)) *vs* (Failure type (Restorable *n*=2/ Non Restorable=13))	The SN method is faster and has fewer mishaps in the removal of MTA and preserves some of the fracture resistance of the tooth compared with conventional method
Mo *et al.* [45]	40 (*n*=20)	crown-amputated first molar, central incisor, first premolar, second molar of maxillary digitized dentition	Fiber post removal	SN	G 1: guided (SN) G 2: freehand (FH)	CBCT	Coronal linear deviation (0.19±0.09 mm) *vs* (1.0.35±0.18 mm) Apical linear deviation (0.54±0.19 mm) *vs* (1.71±0.51 mm) Angular deviation (2.67°±1.07°) *vs* (8.68°±2.46°)	The novel 3D-printed guide system without sleeves, demonstrated greater precision in drilling for fiber post removal compared to the FH technique
Karim *et al.* [42]	60 (*n*=30)	Two-rooted Maxillary first premolars	Separated Endodontic File retrieval	DNS (Navident)	G 1: guided (SN) G 2: FH(under the dental operating microscope)	CBCT (voxel size of 150 µm, 90 kV, 32 mAsec, and 10*6 cm FOV)	Success rate (66.7%) *vs* (83.3%) Time (23±6.67 min) *vs* (12.1±7.25 min) Canal aberration (40%) *vs* (12%) Root canal volume change (3.1 mm^3) *vs* (2.1 mm^3)	Under a 3D video microscope, the hollow tube extractor system demonstrated superior effectiveness compared to the DNS for retrieving separated instruments

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Rohra, *et al.* [46]	22 (*n*=11)	two-rooted maxillary first premolars	retreatment access cavity in a specific canal of multirooted tooth	SN	G 1: guided (SN) G 2: FH	CBCT (Veraview pox 3D R-200 models, at 4×4 FOV, 2.39 mGy, 90 kV, 5 mA)	Volumetric substance loss (11.73±1.85 mm^3) *vs* (27.64±11.34 mm^3) Dentin involvement (27.3%) *vs* (72.7%)	Guided endodontic retreatment in a specific canal of multirooted tooth is more precise, resulting in significantly less tooth substance loss and better preservation of healthy dentin, while effectively exposing the gutta-percha at the canal orifice
Abella Sans *et al.* [43]	48 (*n*=24)	single-rooted human premolar	Fiber post removal	SN	G 1: SN G 2: SN-ultrasonic G 3: non-guided	CBCT (8×8-cm FOV, 0.8 mA, 84 kV and 12-sec exposure time)	Reaching gutta-percha (96%) *vs* (46%) Time (*SN* 5:14 (±3:36) *SN-ultrasonic*) *vs* (26:18 (±13:23)) Root perforation (*n*=1 (4%) *vs* (*n*=13 (54%) Dentin loss (*SN* 0 mm) *SN-ultrasonic* 0.398 (±0.18) mm *vs* (0.39 (±0.17) mm) Deviation (*SN* 0 mm *SN-ultrasonic* −0.00075 (±0.22) mm) *vs* (−0.03 (±0.17) mm)	The SN technique outperformed the conventional ultrasonic tip technique regarding dentin loss, access to the apical gutta-percha, procedure duration, and complications during fiber post removal
Krug *et al.* [44]	24 (*n*=8)	Models of the maxilla, each containing up to four human maxillary central incisors	Fiber post removal	SN	G 1: conventional method by general dentist (CG) G 2: conventional method by a specialist (CS) G 3: guided endodontics (GE) by general dentist	micro-CT scanner (90 kV, tube current 200 µA, 20×20 mm FOV, acquisition time: 2 min, and a voxel size of 39 µm)	Dentin loss (5.32±2.26 mm^3) *vs* (*CG* 7.29±2.44 mm^3 *CS* 13.62±5.76 mm^3 Residual resin/fiberglass (7.24±4.16 mm^3) *vs* (*CG* 8.16±2.54 mm^3 *CS* 6.40±3.64 mm^3) Working time (3.05±1.68 *(Min to access gutta-percha)*, 5.88±1.10 *(complete post/resin removal)*) *vs* (*CG* 6.06±1.82 *(Minutes time to access gutta-percha)*, 7.01±1.74 *(complete post /resin removal)* *CS* 4.96±2.53 *(Minutes time to access gutta-percha)*, 6.87±4.04 *(complete post/resin removal)* Deviation (*n*=4 (13.3%)) vs (*CG n*=6 (20.0%) *CS n*=11 (36.7) Perforation (*n*=0) *vs* (*CG n*=4 (13.3%) *CS n*=6 (20.0%)	The novel guided endodontics technique significantly enhanced the time efficiency and safety of fiber post removal

CBCT, cone-beam computed tomography; FOV, field of view; FH, freehand; SN, static navigation; DNS, dynamic navigation system; CG, conventional method by general dentist; CS, conventional method by a specialist; GE, guided endodontics; CNT: Computer-aided navigation technique; GT: Guided technique; CT: Conventional technique; IAM: Image acquisition method; RA: Retreatment application

Table 3. Risk of bias assessment using the QUIN tool

Author	Clearly stated aims/objectives	Sample size calculation	Sampling technique	Comparison group	Methodology	Operator details	Randomization	Measurement of outcome	Outcome assessor details	Blinding	Statistical analysis	Results	Risk of bias
Ali *et al.* [17]	2	0	1	2	2	2	1	2	2	0	2	2	Low
Janabi *et al.* [41]	2	1	2	2	2	2	1	2	2	0	2	2	Low
Mo *et al.* [45]	2	1	1	1	2	1	0	2	2	0	2	2	Medium
Karim *et al.* [42]	2	1	2	1	2	1	0	2	2	0	2	1	Medium
Rohra *et al.* [46]	2	0	1	1	2	0	0	1	1	0	2	1	High
Abella Sans *et al.* [43]	2	1	2	2	2	2	1	2	2	0	1	2	Low
Krug *et al.* [44]	2	0	1	1	2	1	0	2	2	0	1	2	Medium

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Discussion

The present systematic review aimed to compare the accuracy of guided and conventional endodontic approaches in failed root canal treatments. In clinical procedures, repeated endodontic treatments are usually required to treat teeth with various complications and root canal blockage, in which a conventional approach for retreating them can cause excessive tooth structure loss [47]. It is now accepted that preserving enamel and dentin during endodontic procedures, particularly endodontic retreatments, positively impacts the tooth's biomechanical response to functional occlusal loading and enhances its fracture resistance [48-50]. The primary outcomes assessed were the precision and effectiveness of the guided endodontic technique compared to the conventional technique. Five studies evaluated the time spent between the guided and FH groups [17, 41-44]. Accuracy was assessed using several measures, including coronal and apical deviations [41, 43-45], angular deviation [41, 45], tooth substance loss [41, 43-46], and the number of failed attempts and procedural errors [41-44].

Recent advancements in 3D printing and surface scanning have enabled the development of static guidance systems, where the access drill path is predetermined using CBCT data and transferred to a rigid template [51]. CBCT plays a crucial role in endodontics by providing detailed 3D imaging that helps clinicians visualize complex tooth anatomy, identify hidden structures, and plan precise treatments [52-54]. However, the increased time and costs of intraoral scanning and 3D printing can present challenges. In response to these issues, the DNS has overcome these drawbacks. The key advantages of DNS include its ability to adjust the direction of the access cavity in real time and offer improved visibility of dental structures [55]. Two included studies used DNS as their guided technique [41, 42], and four used the SN technique [43-46]. The included studies used CBCT or micro-CT imaging but with various acquisition properties. Furthermore, there was significant variability among the protocols used in the studies. However, regardless of the technique, no differences were observed in terms of effectiveness or the prevalence of complications.

Although assessing the operators was not the aim of this study, two of the included studies compared clinicians of different experience levels as well and showed that in the case of using SN guidance, no significant differences in performance of fiber post removal were observed between experienced and inexperienced operators [43, 44]. In contrast, Fachin *et al.* indicated a difference in the accuracy of experienced and inexperienced operators in removing fiberglass posts, with experienced operators having higher accuracy [56]. Further studies comparing operators' experience levels will benefit guided endodontics.

Previous systematic reviews, meta-analyses, and scoping reviews have comprehensively assessed guided techniques in surgical and non-surgical endodontics [57-62]. However, it is important to note that the present systematic review specifically focused on comparing the efficacy of conventional and guided endodontics in endodontic retreatments. Research conducted by Langaliya *et al.* [63] highlighted the DNS as an effective method in preserving dentin, achieving superior results in angulation precision, procedural accuracy, and time efficiency during access cavity preparation. All the studies included in this review reported improved accuracy and reduced volumetric loss of tooth structure when using a guided approach, except for one study in which more tooth volume loss and time taken were reported in the guided group, which might be related to operator's experience in dynamic navigation approach which needs high hand-eye coordination [42]. One limitation of this review is the small number of *in vitro* studies, and for a more reliable comparison of guided and freehand techniques in endodontic retreatments, more *in vitro* and *in vivo* studies are needed. Another limitation is the lack of uniformity in data reporting across studies, with heterogeneous parameters used in each. Standardized reporting would enhance the quality of future research. As more studies emerge, comparing DNS and SN as two guided methods could pave the way for the clinical translation of guided endodontics in clinical procedures.

Conclusion

The findings from the included *in vitro* studies suggest that guided endodontics represents a significant advancement in endodontics, particularly for root canal retreatments with a low risk of complications. However, the extrapolation of these results should be cautiously approached due to the limited available evidence. Additional well-designed studies and clinical trials are necessary to further validate its efficacy and address the associated challenges.

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Conflict of interest
None.

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Authors' contributions

Conceptualization: MS/STA, Methodology: MS/PS/STA, Formal analysis and investigation: MS/PS/STA Writing-original draft preparation: PS/STA, Writing-review and editing: MS/STA, Supervision: MS. All authors read and approved the final manuscript.

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