ECRONICON OPEN ACCESS

EC DENTAL SCIENCE
Review Article

Dynamic Navigation in Endodontics: A Systematic Review of Accuracy, Dentin Preservation, and Clinical Feasibility for Minimally Invasive Access

Yehudah Hammond, Seger Moore and Leonard B Goldstein*

Arizona School of Dentistry and Oral Health, A.T. Still University, Mesa, Arizona, USA

***Corresponding Author:** Leonard B Goldstein, Arizona School of Dentistry and Oral Health, A.T. Still University, Mesa, Arizona, USA.

Received: April 24, 2026; **Published:** June 12, 2026

Abstract

Objectives: We examined the literature on dynamic navigation (DN) for minimally invasive and predictable access, and compared its accuracy, dentin preservation, efficiency, and complications with those of the freehand and static approaches.

Materials and Methods: This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines. PubMed, Scopus, Web of Science, and the Cochrane Library were searched (2013-2023) using terms related to DN and guided endodontics. Due to substantial methodological heterogeneity, a narrative synthesis was performed. We evaluated risk of bias using QUIN, RoB 2, and ROBINS-I.

Results: We included 15 studies: seven *in vitro*, five clinical, and three comparatives. The mean linear deviation was 0.28-0.47, 0.39-0.56, and 0.67-1.20 mm for DN, static guidance, and freehand, respectively. Mean angular deviation was 1.9-3.2°, 2.1-3.8°, and 4.5-7.0° for DN, static guidance, and freehand, respectively. DN was associated with a better dentin preservation than the freehand technique, and it was comparable to static guidance. Preparation time was broadly similar across methods, with static approaches having slightly longer times.

Conclusion: DN is associated with a high accuracy, improved dentin preservation relative to freehand access, and intra-operative adaptability that aligns with minimally invasive endodontic principles.

Clinical Relevance: Cost, training requirements, and the limited number of robust clinical studies restrict routine DN use. Larger, randomized controlled trials and standardized outcome reporting are required to confirm long-term clinical and patient-centered benefits.

Keywords: *Dynamic Navigation; Guided Endodontics; Minimally Invasive Endodontics; CBCT; Root Canal Access; Dentin Preservation*

Introduction

Successful root canal therapy involves accurate location of accessible canals and minimally invasive preparation of access while maintaining critical tooth structure. The most used method to access the canals is the traditional freehand technique; however, it carries the risk of unnecessary dentin removal, perforations, and missed canals, which can weaken the tooth and jeopardize a favorable long-term prognosis [1-4]. These risks are higher in teeth that have undergone calcification and/or teeth with anatomic complexities that affect visualization and tactile landmarks. Calcific metamorphosis and pulp canal obliteration can be caused by trauma, age, restorations, and other factors, and lead to challenges in obtaining a proper diagnosis and performing successful treatment [5-7].

To address these limitations, guided approaches have been developed. Static navigation uses cone-beam computed tomography (CBCT)-based planning and prefabricated templates to aid in directing the bur along a predetermined pathway. Compared to freehand guidance, static guidance access improves accuracy but restricts intra-operative adaptability if complications arise or the anatomy varies from that seen during pre-planning [8-10]. Dynamic navigation (DN) offers intra-operative flexibility while maintaining the advantages of CBCT and three-dimensional imaging. Using optical tracking, DN simultaneously tracks the bur, visualizes its position and angulation throughout the procedure, and allows pathway adjustments, thus enabling minimally invasive endodontics (MIE) with greater precision and flexibility [11-15] (Figure 1).

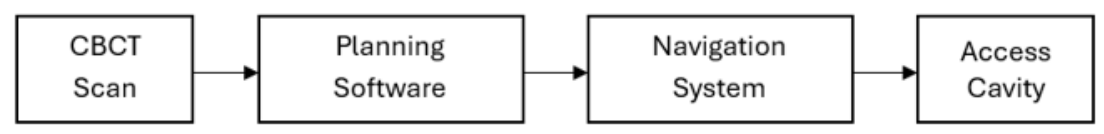

Figure 1: *Workflow schematic of dynamic navigation.*

Preliminary *in vitro* studies support the benefit of DN over the freehand technique, with reduced linear and angular deviation and accuracy comparable to, or slightly surpassing, static guides [16-19]. Some studies suggest that both freehand and DN may preserve more dentin than static guidance, possibly because static templates may encourage slightly more generous access preparations [16,17]. Narrative and systematic reviews have also suggested that DN can reduce the incidence of iatrogenic errors and improve canal location in cases of calcification, although the operator learning curve, associated costs, and workflow demands are practical considerations when using this approach [20-23].

Although these developments are promising, evidence supporting DN is conflicting. Most studies are *in vitro* experiments conducted in idealized conditions, and the available clinical studies are few small heterogeneous ones. This restricts the ability to relate technical improvements to real-world outcomes, such as efficiency and complication rates, and to patient-centered metrics, including patient comfort or satisfaction. Furthermore, the present review focuses on DN use for non-surgical access preparation. Studies on DN in surgery sometimes report patient-centered outcomes such as comfort or cost, but these measures are rarely reported for non-surgical DN and are considered secondary or exploratory in this review.

Given the current imbalance with extensive *in vitro* research and limited clinical investigation, there is a need to systematically synthesize the literature to address the question of whether DN techniques produce clinically meaningful benefits compared with freehand and static guidance approaches. Therefore, we evaluated DN for minimally invasive, predictable access, and compared accuracy, dentin preservation, efficiency, and complications between the freehand and static approaches [11,16-19,24,25].

Methods

Design

We performed a systematic review using the PRISMA 2020 framework [26]. The protocol was prospectively registered on the Open Science Framework (OSF; Registration ID: WYQU5, https://osf.io/wyqu5; DOI: 10.17605/OSF.IO/WYQU5).

Screening occurred in two stages: an initial title and abstract review, followed by full-text assessment according to predefined eligibility criteria.

Databases and search terms

A systematic literature search was performed using PubMed, Scopus, Web of Science, and the Cochrane Library on October 15, 2025, and limited to articles published between January 1, 2013, and December 31, 2023.

We used a combination of controlled vocabulary (for example, MeSH terms) and free-text terminology, including "dynamic navigation," "guided endodontics," "minimally invasive access," "CBCT endodontics," and "optical tracking endodontics," combined with Boolean operators. Full, reproducible search strings for each database are provided in Online Resource 1, as recommended by PRISMA 2020.

Online Resource 1: Full Search Strategies
PubMed: ("dynamic navigation"[Title/Abstract] OR "guided endodontics"[Title/Abstract] OR "CBCT endodontics"[Title/Abstract] OR "optical tracking endodontics"[Title/Abstract]) AND ("2013/01/01"[Date - Publication]: "2023/12/31"[Date - Publication])
Scopus: TITLE-ABS-KEY ("dynamic navigation" OR "guided endodontics" OR "minimally invasive access" OR "CBCT endodontics" OR "optical tracking endodontics") AND PUBYEAR > 2012 AND PUBYEAR < 2024
Web of Science: TS=("dynamic navigation" OR "guided endodontics" OR "minimally invasive access" OR "CBCT endodontics" OR "optical tracking endodontics") AND PY=(2013-2023)
Cochrane Library: "dynamic navigation" OR "guided endodontics" OR "CBCT endodontics" OR "minimally invasive access" OR "optical tracking endodontics" in Title, Abstract, or Keywords (2013-2023).

Table

All identified records were exported into a reference management program and manually screened to identify and remove duplicates. The reference lists of included studies and key review articles were screened manually. Forward citation tracking was performed using Google Scholar. Grey literature and non-peer-reviewed sources (for example, theses and conference abstracts) were not included because of inconsistent methodological reporting.

Inclusion criteria:

1. **Study design:** Randomized clinical trial, non-randomized clinical study, or controlled *in vitro* study.
2. **Topic:** Use of DN for non-surgical endodontic access preparation.
3. **Outcomes:** At least one measurable outcome related to accuracy, dentin preservation, preparation time, or complication rates.
4. **Reporting:** Sufficient methodological detail to allow meaningful extraction and comparison of DN with freehand and/or static-guided access.

Exclusion criteria:

1. Case reports, case series without quantitative outcomes, editorials, technique notes, or narrative reviews.
2. Exclusive focus on implant navigation with no application to endodontics.
3. Non-English publications.
4. No extractable data or insufficient methodological description.
5. Exclusive evaluation of DN for endodontic microsurgery, unless non-surgical access outcomes were separately reported.

Primary outcomes:

- **Accuracy:** Linear deviation (mm) and angular deviation (degrees) between planned and actual access paths.
- **Dentin preservation:** Volume of removed dentin (mm^3) during access preparation.

- **Preparation time:** Total access preparation time (minutes).
- **Complications:** Incidence of perforations, missed canals, or other procedural errors.

These were objective measures to compare DN with static-guided and freehand approaches to root canal access preparation in terms of precision, conservation, efficiency, and safety.

Secondary outcomes

- **Patient comfort:** Pain, anxiety, and/or satisfaction with treatment.
- **Economic feasibility:** Cost-related considerations such as equipment costs, workflow efficiency, and potential reduction in retreatment.
- **Operator learning curve:** Descriptive or quantitative information on number of cases or time required to attain proficiency with DN.

These outcomes were treated as exploratory because they were infrequently and heterogeneously reported.

Data extraction and analysis

A single reviewer performed extracted data using a standardized data collection form. Extracted variables included study design, sample size, tooth type, navigation system used, comparator technique (freehand and/or static guidance), imaging parameters, measurement methods, and outcomes (accuracy, dentin removal, preparation time, and complications).

Due to substantial heterogeneity in methodology and reported outcomes, a meta-analysis was not feasible. Instead, a narrative synthesis was conducted when statistical pooling was inappropriate. Studies were grouped by design (*in vitro* versus clinical) and comparator (DN versus freehand, DN versus static guidance). Direction-of-effect summaries were used to characterize trends in favor of or against DN.

The study selection process is provided in figure 2.

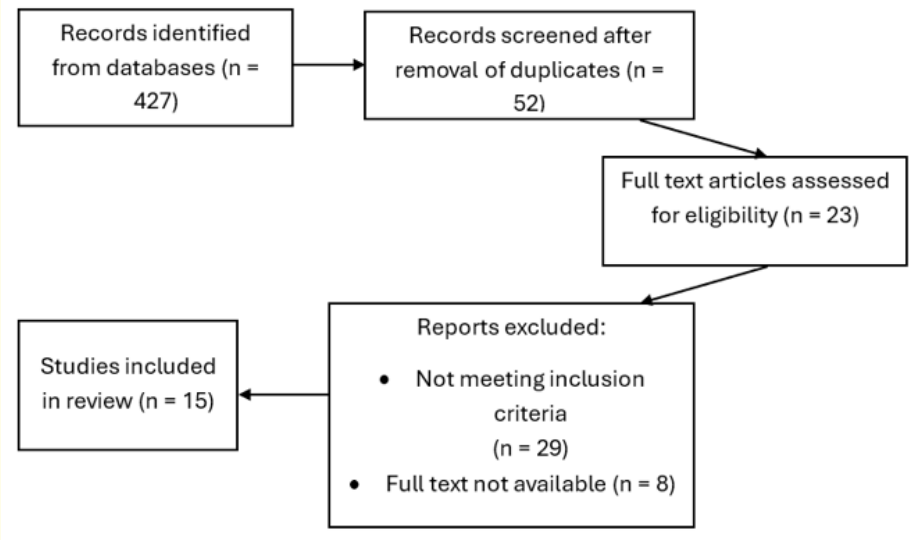

Figure 2: *PRISMA diagram.*

Risk of bias assessment:

- ***In vitro* studies:** The Quality Assessment Tool for *In Vitro* Studies (QUIN) was used, which evaluates twelve methodological domains and produces an overall quality rating (low, moderate, or high).
- **Randomized clinical trial(s):** The revised Cochrane Risk of Bias Tool (RoB 2) was applied across five domains: randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result.
- **Non-randomized clinical studies:** The Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool was used.

Results

Study selection

The electronic search identified 427 records (PubMed, n = 169; Scopus, n = 47; Web of Science, n = 89; Cochrane Library, n = 122). After removal of duplicated and irrelevant records, 52 titles and abstracts were screened. Of these, 23 full-text articles were assessed for eligibility. Fifteen studies met the inclusion criteria.

The study selection process is summarized in figure 2 (PRISMA flow diagram).

Study characteristics

The fifteen included studies comprised seven *in vitro,* five clinical studies, and three studies were explicitly comparative in design (DN versus freehand and/or static guidance). Not all studies reported every primary outcome. Table 1 shows the number of contributing studies for each endpoint (accuracy, dentin preservation, preparation time, and complications).

Study characteristics including design, sample size, tooth type, navigation method(s), comparator technique, and measured outcomes are presented in table 1. The overall pattern of comparative outcomes across navigation methods is summarized in table 2.

Risk of bias assessment

***In vitro* studies (QUIN assessment):** *In vitro* studies had moderate-to-high methodological quality. Common limitations included:

- Lack of blinding of operators and/or outcome assessors,
- Absent or unclear sample size justification, and
- Inconsistent randomization procedures.

Most studies presented the following strengths: standardized imaging protocols and use of validated software for linear, angular, and volumetric measurements.

Clinical studies

The randomized clinical trial demonstrated an overall risk of bias of "some concerns," primarily related to unclear allocation concealment and incomplete reporting of assessor blinding (Table 3). The non-randomized studies presented moderate-to-serious concerns across several ROBINS-I domains, particularly confounding and selection of participants into the study (Table 4 and 5).

Study	Reporting	Sample Size Justification	Randomization	Blinding	Standardization	Imaging Protocol	Measurement Validity	Overall Rating
Jain 2020 [12]	Adequate	Not reported	Not reported	No	Moderate	Yes	Yes	Moderate
Torres 2021 [13]	Good	Partial	Yes	No	Strong	Yes	Yes	High
Yuk 2022 [15]	Adequate	Not reported	Not clear	No	Moderate	Yes	Yes	Moderate
Zubizarreta-Macho 2020 [19]	Good	Partial	Yes	No	Strong	Yes	Yes	High
Saxena 2022 [22]	Good	Yes	Yes	Yes	Strong	Yes	Yes	High

Table 3: *Quality assessment tool for in vitro studies (QUIN) assessment for in vitro studies.*

Domain	Judgment	Reason
Randomization process	Some concerns	Allocation concealment unclear
Deviations from intended interventions	Low	No deviations likely
Missing outcome data	Low	No major loss to follow-up
Measurement of outcomes	Some concerns	Assessor blinding unclear
Selection of reported results	Low	All predefined outcomes reported
Overall	Some concerns	Issues mainly related to concealment and blinding

Table 4: *Cochrane risk of bias tool (RoB 2) assessment for randomized controlled trials [24].*

Domain	Judgment	Reason
Confounding	Serious	No adjustment for operator variability or case complexity
Selection of participants	Moderate	Non-randomized recruitment
Classification of interventions	Low	Clear DN vs static definition
Deviations from intended interventions	Moderate	Differences in workflow not fully controlled
Missing data	Low	Minimal missing outcome data
Measurement of outcomes	Moderate	Assessor blinding not clearly described
Selection of reported results	Low	Reported all prespecified outcomes
Overall	Moderate-Serious risk	Driven mainly by confounding and selection bias

Table 5: *The risk of bias in non-randomized studies of interventions (ROBINS-I) assessment for non-randomized studies [25].*

DN: Dynamic Navigation.

Accuracy outcomes

In vitro: Five of the seven *in vitro* studies reported linear and/or angular deviation:

- DN: Mean linear deviation, 0.28-0.47 mm.
- Static guidance: Linear deviation, 0.39-0.56 mm.
- Freehand access: Higher deviation, 0.67-1.20 mm.

For angular deviation:

- DN: 1.9-3.2°.
- Static guidance: 2.1-3.8°.
- Freehand: 4.5-7.0°.

Sample sizes for *in vitro* experiments typically ranged from 20 to 60 teeth. Representative pooled data for key comparative studies are summarized in table 2.

Clinical: The randomized clinical trial [24] reported a lower deviation for DN than that for freehand:

- DN linear deviation: ≈ 0.31 mm.
- Freehand linear deviation: ≈ 0.82 mm.
- DN angular deviation: ≈ 2.6°.
- Freehand angular deviation: ≈ 6.9°.

No clinical study directly compared accuracy outcomes between DN and static guidance.

Dentin preservation

In vitro: Three *in vitro* studies reported volumetric dentin removal:

- DN: 3.8-5.2 mm^3.
- Freehand: 7.0-9.4 mm^3.
- Static guidance: 5.0-6.3 mm^3 (slightly higher than DN in two studies).

Variation in dentin volume measurements reflected differences in CBCT voxel size, segmentation thresholds, and software used.

Clinical: One clinical study [24] reported dentin removal for access:

- DN: ≈ 4.6 mm^3.
- Freehand: ≈ 8.1 mm^3.

Static guidance was not evaluated clinically for dentin preservation.

Procedural efficiency

In vitro: Four *in vitro* studies reported the preparation time:

- DN: 4.8-6.5 minutes.

- Freehand: 5.5-7.8 minutes.
- Static guidance: 6.0-8.2 minutes.

The setup time for DN was generally longer than that for freehand because DN requires system calibration and pre-operative plannings; however, the active cutting time was similar or slightly shorter in some studies. Most reports did not fully standardize planning and calibration in the total time measures.

Clinical: The randomized clinical trial found [24]:

- DN access time: ≈ 5.4 minutes.
- Freehand: ≈ 6.1 minutes.

Static guidance was not clinically evaluated for procedural efficiency.

Complications and iatrogenic errors

Complications were inconsistently reported across studies.

In vitro:

- Freehand access: Perforations in 2 - 6% of samples.
- DN access: No perforation in any *in vitro* study.
- Static guides: Low perforation rates, 0 - 1%.

Missed canal rates:

- DN: 0%.
- Freehand: up to 18%.
- Static guidance: 0-5%.

Clinical: Only one clinical study provided data on complication and reported no perforations in the DN or freehand groups. Missed canal rates were not systematically reported in clinical studies.

Patient-centered outcomes

Only one clinical study included limited patient-related measures. Chen., *et al.* [24] evaluated postoperative discomfort and reported no statistically significant difference between the DN and freehand groups. No included clinical studies assessed anxiety, satisfaction, or patient experience during access preparation. Most evidence on patient comfort originates from DN-assisted microsurgical studies, which were not included in the primary analysis for non-surgical access and are cited only contextually.

Operator learning curve

No included study quantitatively evaluated the operator learning curve. Two studies offered qualitative comments that DN required additional training time for calibration, hand-eye coordination, and workflow adaptation, but reported no structured metrics.

Cost and economic considerations

None of the primary DN access studies reported direct cost data, cost-effectiveness analyses, or formal economic evaluations. Cost-related information was found only in narrative reviews and expert commentaries and was therefore not extractable for systematic synthesis.

Table 6 shows a summary of the overall direction of effect and certainty of the evidence for each primary outcome

Outcome	Evidence Base	Direction of Effect	Certainty
Linear deviation	5 *in vitro*, 1 RCT	DN > FH; DN ≈ SG	Low-Moderate
Angular deviation	5 *in vitro*, 1 RCT	DN > FH; DN ≈ SG	Low-Moderate
Dentin preservation	3 *in vitro*, 1 clinical	DN > FH; DN ≈ SG	Low
Procedure time	4 *in vitro*, 1 clinical	DN ≈ FH (slightly faster active time in some studies)	Low
Complications	3 *in vitro*, 1 clinical	DN/SG: low perforations; FH: higher errors	Low
Patient-centered outcomes	1 clinical (microsurgery, secondary)	No clear difference DN vs comparator	Very Low
Learning curve	0 quantitative; 2 qualitative	DN requires additional training	Very Low
Economic outcomes	None	Not assessed	Very Low

Table 6: *Summary of direction-of-effect for key outcomes.*

DN: Dynamic Navigation; RCT: Randomized Controlled Trial; FH: Freehand; SG: Static Guidance.

Discussion

Interpretation of findings

DN consistently demonstrated improved accuracy and reduced dentin removal compared with freehand access, with performance broadly comparable to, and sometimes slightly better than, static guidance. These findings align with the conceptual advantages of DN: three-dimensional planning combined with real-time tracking to maintain a precise trajectory while allowing intra-operative adjustment.

Comparison with other access methods

Freehand access remains the most flexible and widely used method for endodontic access. It allows immediate intra-operative adaptation without specialized equipment. However, in reviewed studies, it consistently exhibited greater linear and angular deviation and higher rates of iatrogenic events in the reviewed studies. Static guidance offers predictable accuracy but its use is limited by adaptability, because any major change in strategy requires designing new guidance.

DN can be viewed as a hybrid approach that combines the accuracy of guidance with the adaptability of freehand techniques. *In vitro*, DN generally outperforms freehand and slightly surpasses static guidance in accuracy metrics, but the absolute differences between DN and static guidance are small, and direct clinical comparisons are lacking. The practical significance of these small numerical improvements is uncertain, especially in patients with a relatively predictable anatomy.

A more nuanced interpretation is that DN is likely to provide its greatest benefit in complex situations such as teeth with calcified canals, unusual anatomy, or retreatment cases where freehand access has a higher risk of deviation, perforation, or missed canals and static guides may be difficult to design or insufficiently flexible.

Biomechanical and clinical implications

MIE emphasizes the preservation of coronal, cervical, and radicular dentin to support long-term biomechanical stability. By confining access within a narrower, preplanned path, DN theoretically helps conserve pericervical dentin, which plays a key role in distributing functional stresses and maintaining fracture resistance [23]. *In vitro* dentin preservation data support this concept, showing lower volumetric removal with DN compared with freehand and similar or slightly better conservation than static guidance.

However, nearly all biomechanical data related to access design are derived from laboratory models. No included human study evaluated long-term fracture resistance, cuspal deflection, or tooth survival as a function of DN-guided access. Clinically, DN appears most promising in challenging cases, such as pulp canal obliteration or complex anatomy, where preserving tooth structure while securely locating the canal is particularly difficult. However, because complication rates and longer-term outcomes were sparsely reported and often based on small samples, conclusions regarding safety and durability remain tentative.

Strengths and Limitations of Evidence

This review had some limitations:

- **Study design:** Most quantitative data were derived from *in vitro* studies that do not fully replicate clinical challenges such as patient movement, access limitations, restorative constraints, and occlusal loading. Only one randomized controlled trial was identified, with "some concerns" for risk of bias, and one non-randomized clinical study had moderate-to-serious risk of bias.
- **Outcome variability:** Definitions of linear and angular deviation, measurement landmarks, and reporting formats varied across studies. Volumetric dentin removal measurements used different segmentation protocols and voxel sizes, limiting direct comparability. Preparation time definitions were inconsistent, with some studies including only active cutting and others partly or fully incorporating planning and calibration time.
- **Patient-centered outcomes:** Very few patient-related outcomes were reported in the context of non-surgical DN access. The included clinical studies did not evaluate anxiety, satisfaction, and long-term tooth survival.
- **Publication bias:** The predominance of positive findings, small sample sizes, and incomplete reporting of funding and industry involvement raise the possibility of publication bias.
- **Risk of bias and review processes:** Across QUIN, RoB 2, and ROBINS-I assessments, common concerns included limited blinding, inconsistent operator calibration, lack of preregistered protocols in primary studies, and no prospective sample size calculations. In this review, a single reviewer screened and extracted data; this increased the risk of selection and extraction bias.

These limitations suggest that while DN is promising, the current evidence should be interpreted with caution.

Practical considerations for clinical adoption

Beyond technical metrics, DN adoption depends on feasibility in everyday practice. Costs associated with CBCT imaging, navigation hardware, software licenses, and facility modifications can be substantial. Clinicians must also invest time in training and integrating DN workflows into their existing clinical routines, including calibration, registration, and coordination with staff.

Given that only one clinical study directly examined efficiency and that none reported cost or cost-effectiveness data, it is not possible to determine whether DN offers net time savings or economic advantages. Factors such as case complexity, operator experience, practice volume, and reimbursement models are likely to influence whether DN provides sufficient value to justify the initial and ongoing investment.

Future Research Directions

1. Larger multicenter randomized controlled trials comparing DN, static guidance, and freehand access in real-world clinical settings, with adequate sample sizes and rigorous risk-of-bias control.
2. Standardized outcome definitions and measurement protocols for linear and angular deviation, dentin removal, and preparation time to allow meaningful comparison and pooling across studies.
3. Comprehensive complication reporting, including perforation rates, missed canal incidence, and other iatrogenic events, with clear denominators and follow-up data.
4. Patient-centered outcome assessment, such as postoperative pain, analgesic use, anxiety, satisfaction, treatment duration, and long-term tooth survival.
5. Economic evaluations, including cost-benefit and cost-effectiveness analyses that consider equipment, training, workflow modifications, and potential reductions in retreatment.
6. Operator learning curve studies, using validated performance metrics to quantify how quickly clinicians achieve proficiency in DN.
7. Retreatment and complex-case applications, where canal anatomy is altered or obscured and traditional freehand access carries higher risk.

Emerging technologies such as artificial intelligence-assisted planning, automated path optimization, and real-time error detection may further refine DN workflows and reduce the learning curve [27]; these advances require systematic evaluation.

Conclusion

DN is an accurate method for accessing root canals without being overly invasive. It has a higher accuracy and ensures more favorable dentin preservation than freehand access, aligning with the principles of MIE, reducing iatrogenic damage risk, and reducing retreatment needs. However, equipment cost, training requirements, workflow demands, and no high-level clinical evidence limits DN use.

Acknowledgements

The authors thank the faculty and staff of the Arizona School of Dentistry and Oral Health for their support and access to resources used in completing this project. No individuals other than the listed authors contributed to the conception, data extraction, or analysis of this review.

Funding Statement

No external funding was received for this study.

Conflict of Interest Disclosure

The authors declare no conflicts of interest related to this work.

Ethics Approval Statement

Ethics approval was not required for this systematic review because it involved the synthesis of published data and did not involve human participants, identifiable data, or animal subjects.

Data Availability Statement

All data used in this review are derived from publicly available published studies. Additional data are available from the corresponding author upon reasonable request.

Registration

Open Science Framework (OSF): DOI 10.17605/OSF.IO/WYQU5.

Bibliography

1. Boren DL., *et al*. "Long-term survival of endodontically treated teeth at a public dental specialist clinic". *Journal of Endodontics* 41.2 (2015): 176-181.
2. Estrela C., *et al*. "Common operative procedural errors and clinical factors associated with root canal treatment". *Brazilian Dental Journal* 28.2 (2017): 179-190.
3. Neelakantan P., *et al*. "Present status and future directions: minimally invasive root canal preparation and periradicular surgery". *International Endodontic Journal* 55.S4 (2022): 845-871.
4. Tang W., *et al*. "Identifying and reducing risks for potential fractures in endodontically treated teeth". *Journal of Endodontics* 36.4 (2010): 609-617.
5. Holcomb JB and Gregory WB Jr. "Calcific metamorphosis of the pulp: its incidence and treatment". *Oral Surgery, Oral Medicine, Oral Pathology* 24.6 (1967): 825-830.
6. McCabe PS and Dummer PMH. "Pulp canal obliteration: an endodontic diagnosis and treatment challenge". *International Endodontic Journal* 45.2 (2012): 177-197.
7. Pettiette MT., *et al*. "Potential correlation between statins and pulp chamber calcification". *Journal of Endodontics* 39.9 (2013): 1119-1123.
8. Connert T., *et al*. "Present status and future directions-guided endodontics". *International Endodontic Journal* 55.S4 (2022): 995-1002.
9. Kulinkovych-Levchuk K., *et al*. "Guided endodontics: a literature review". *International Journal of Environmental Research and Public Health* 19.21 (2022): 13900.
10. Ribeiro D., *et al*. "Guided endodontics: static vs dynamic computer-aided techniques—a literature review". *Journal of Personalized Medicine* 12.9 (2022): 1516.
11. Chong BS., *et al*. "Computer-aided dynamic navigation: a novel method for guided endodontics". *Quintessence International* 50.3 (2019): 196-202.
12. Jain SD., *et al*. "3-Dimensional accuracy of dynamic navigation technology in locating calcified canals". *Journal of Endodontics* 46.6 (2020): 839-845.
13. Torres A., *et al*. "Dynamic navigation: a laboratory study on guided root canal treatment's accuracy and potential use". *International Endodontic Journal* 54.9 (2021): 1659-1667.
14. Wei X., *et al*. "Expert consensus on digital guided therapy for endodontic diseases". *International Journal of Oral Science* 15 (2023): 54.
15. Yuk M., *et al*. "A literature review of minimally invasive endodontic access cavity-past, present and future". *European Endodontic Journal* 7.1 (2022): 190-199.
16. Huth KC., *et al*. "Comparing accuracy in guided endodontics: dynamic real-time navigation, static guides, and manual approaches for access cavity preparation - an *in vitro* study using 3D printed teeth". *Clinical Oral Investigations* 28 (2024).

17. Jonaitytė EM., *et al*. "Accuracy of dynamic navigation for non-surgical endodontic treatment: a systematic review". *Journal of Clinical Medicine* 11.12 (2022): 3441.

18. Langaliya A., *et al*. "Does the dynamic navigation system preserve more dentine?-A systematic review". *BMC Oral Health* 24 (2024): 678.

19. Zubizarreta-Macho Á., *et al*. "Accuracy of computer-aided dynamic navigation compared to computer-aided static procedure for endodontic access cavities: an *in vitro* study". *Journal of Clinical Medicine* 9.1 (2020): 129.

20. Fouad EM and Abdelbaky M. "Dynamic navigation: how far would it go in endodontics?" *Journal of Dentistry* 121 (2022): 103992.

21. Ren S., *et al*. "Guided endodontics in applying personalized mini-invasive treatment in clinical cases: a literature review". *The Saudi Dental Journal* 37 (2025): 20.

22. Saxena P and Gupta S. "Static vs. dynamic navigation for endodontic microsurgery: a comparative review". *Journal of Oral Biology and Craniofacial Research* 12.4 (2022): 410-412.

23. Vasudevan A., *et al*. "Dynamic navigation in guided endodontics-a systematic review". *European Endodontic Journal* 7 (2022): 81-91.

24. Chen C., *et al*. "Comparison of accuracy and operation time in robotic, dynamic, and static-assisted endodontic microsurgery: an *in vitro* study". *Journal of Endodontics* 50 (2024): 1448-1454.

25. Chen C., *et al*. "Patient-centred outcome assessment of static and dynamic navigation-aided endodontic microsurgery: a randomized controlled trial". *Journal of Endodontics* 51.6 (2025): 666-673.

26. Page MJ., *et al*. "The PRISMA 2020 statement: an updated guideline for reporting systematic reviews". *British Medical Journal* 372 (2021): 71.

27. Karim M., *et al*. "The role of artificial intelligence in enhancing nurses' work-life balance". *Journal of Medicine, Surgery, and Public Health* 3 (2024): 100135.

Volume 25 Issue 5 May 2026