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Dynamic Navigation in Guided Endodontics – A Systematic Review

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ABSTRACT

Objective: The objective of this systematic review was to comprehensively assess the literature regarding the applications, accuracy, advantages and limitations of dynamic navigation in endodontics.

Methods: Case reports and laboratory studies in the English language, which used the Dynamic Navigation System (DNS) for endodontic application and assessed the accuracy of treatment, the time required for treatment and iatrogenic errors were included. PubMed, Scopus, Embase and Web of Science were searched for eligible articles (up to July 2021). Additional hand searching of four peer-reviewed endodontic journals and a grey literature search were also carried out. A risk of bias assessment was done using the Joanna Briggs Institute (JBI) critical appraisal checklists. Data were extracted based on endodontic application of DNS, tooth type, DNS brand, accuracy, iatrogenic errors, and time taken, followed by qualitative analysis.

Results: Fourteen articles (three case reports and eleven *in-vitro* studies) met the eligibility criteria and were included. The quality assessment revealed a low risk of bias, with mean scores of 83.34% for case reports and 84.09% for *in-vitro* studies. DNS was used for various clinical applications such as access cavity preparation, pulp canal obliteration, endodontic retreatment and microsurgery. The DNS brands used were Navident, X-guide, ImplaNav, and DENACAM. Due to the nature of the component studies, meta-analysis was not possible.

Conclusion: Challenging clinical situations like pulp canal obliteration, conservative access preparation, endodontic retreatment and microsurgery can be managed efficiently with fewer iatrogenic errors in a shorter time using DNS. However, this systematic review's evidence is low since the included articles are either case reports or *in-vitro* studies. Clinical studies are needed to test DNS efficacy among operators, including those who are less proficient and compare the accuracy of currently available systems.

Keywords: Dynamic navigation, endodontic access, navident, periapical surgery, pulp canal obliteration, systematic review

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HIGHLIGHTS

- Challenging endodontic situations requiring high levels of precision can be handled successfully using DNS.
- Unlike static-guided procedures, real-time re-orientation of drill paths is possible in DNS, reducing iatrogenic errors.
- No comparative clinical studies using DNS have been carried out to date, providing future research scope.
- Four systems (Navident, X-guide, ImplaNav, and DENACAM) have been reported in the literature, but their efficacy is yet to be compared.

INTRODUCTION

Guided endodontics is a novel approach used in the management of obliterated root canals (1, 2), autotransplantation (3) and periradicular surgery (4, 5). Guided endodontics can be either static or dynamic. The static type involves the fabrication of 3-dimensional (3D) printed templates using cone-beam computed tomography (CBCT) images, surface scans and virtual imaging software (6, 7). A systematic review on static guided endodontics concluded that it is a clinical procedure which allows for safe, accurate and predictable negotiation of sclerosed canals and minimises iatrogenic damage during periradicular surgery (7).

The dynamic navigation system (DNS) is a computer-aided guided technology initially developed for accurate implant placement (8). The computer provides real-time feedback to the clinician regarding the drill path being prepared during treatment (9). The system uses multiple cameras and motion tracking devices attached to the dental handpiece and patient, and continuously compares the created path with the planned drill path using particular software on the CBCT images of teeth (8, 10). Currently, DNS has been used in endodontics for accessing obliterated root canals (9) and for more precise periapical surgery (11).

Multiple clinical applications using computer-aided navigation are emerging, and thus, a systematic review and quality assessment of literature is needed to better understand this new treatment concept. Hence, this systematic review aimed to assess literature regarding the applications, accuracy, advantages, and limitations of DNS in endodontics.

MATERIALS AND METHODS

Protocol and registration

This systematic review was reported following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (12), and the protocol was registered with the PROSPERO (International prospective register of systematic reviews) database under protocol number: CRD42021231643.

Research question (PICOS)

What are the applications, accuracy, advantages and limitations of dynamic navigation in endodontics?

- Population: Teeth with difficult access to root canals (calcified canals/ teeth with malformations) or teeth requiring endodontic microsurgery or other clinical scenarios (if any)
- Intervention: Dynamic navigation used for endodontic application
- Comparison: Conventional (freehand) approach used for the same scenario
- Outcome: Accuracy, iatrogenic errors, time taken, advantages and limitations of DNS
- Study design: Case reports, *in-vitro* and *ex-vivo* studies.

Eligibility criteria

The inclusion criteria were: (i) applications/ uses of dynamic navigation in endodontics, (ii) *in-vitro* or *ex-vivo* studies that assessed the accuracy of treatment, time taken to perform a procedure, iatrogenic errors when DNS was used, (iii) case reports that assessed efficiency, accuracy and limitations of DNS.

The exclusion criteria were: (i) articles in languages other than English, (ii) narrative reviews, (iii) experts' opinions or personal comments and (iv) guideline reports.

Literature search

Two reviewers (A.V., S.S.) performed a comprehensive literature search from the following electronic databases: *PubMed, Scopus, Embase* and *Web of Science* for articles until July 2021. Additionally, a grey literature search was conducted in OpenGrey (*opengrey.org*), and four peer-reviewed scientific journals (*Journal of Endodontics, International Endodontic Journal, European Endodontic Journal, Australian Endodontic Journal*) were hand-searched for relevant literature.

Study selection

Two researchers (A.V., S.S.) independently reviewed the literature to identify articles that met the eligibility criteria. Databases were searched for relevant publications with Medical Subject Headings, keywords and their combinations, as given in Table 1. Discrepancies were resolved by discussion with a senior endodontist (V.N.).

Scientific merit assessment

The methodological quality of the included articles was assessed by two evaluators (A.V., S.S.) using the Joanna Briggs

TABLE 1. Terms and filters used for electronic database search

Database	Search strategy	Filters
PubMed	((((((dynamic navigation) OR (computer aided technology)) OR (computer-aided navigation)) OR (computer-assisted treatment)) OR (image-guided treatment)) OR (real-time tracking)) AND (((endodontic*) OR root canal*))	Sort by: Best Match Filters activated: Humans
Web of Science	(TS=(dynamic navigation OR dynamic guidance OR computer aided technology OR guided endodontics OR computer-aided navigation OR computer-assisted treatment OR image-guided treatment OR real-time tracking OR navigation system) AND (TS=(pulp canal calcification OR pulp canal obliteration OR calcified canal* OR calcific metamorphosis OR access cavity OR conservative access OR minimally invasive endodontics OR dynamic navigation surgery OR microsurgery OR Navident)	WC=(Dentistry, Oral Surgery & Medicine) AND LANGUAGE: (English)
Scopus	((((((dynamic AND navigation) OR (computer AND aided AND technology)) OR (computer-aided AND navigation)) OR (computer-assisted AND treatment)) OR (image-guided AND treatment)) OR (real-time AND tracking)) AND (((((((pulp AND canal AND calcification) OR (pulp AND canal AND obliteration)) OR (calcified AND canals)) OR (access AND cavity)) OR (minimally AND invasive AND endodontics)) OR (endodontic AND surgery)) OR (microsurgery))	(LIMIT-TO (SUBJAREA, "DENT")) AND (LIMIT-TO (LANGUAGE, "English"))
Embase	dynamic navigation OR dynamic guidance OR computer aided technology OR guided endodontics OR computer-aided navigation OR computer-assisted treatment OR image-guided treatment OR real-time tracking OR navigation system {Including Related Terms} AND pulp canal calcification OR pulp canal obliteration OR calcified canals OR calcific metamorphosis OR access cavity OR conservative access OR minimally invasive endodontics OR dynamic navigation surgery OR microsurgery OR Navident {Including Related Terms}	Limit to: English language

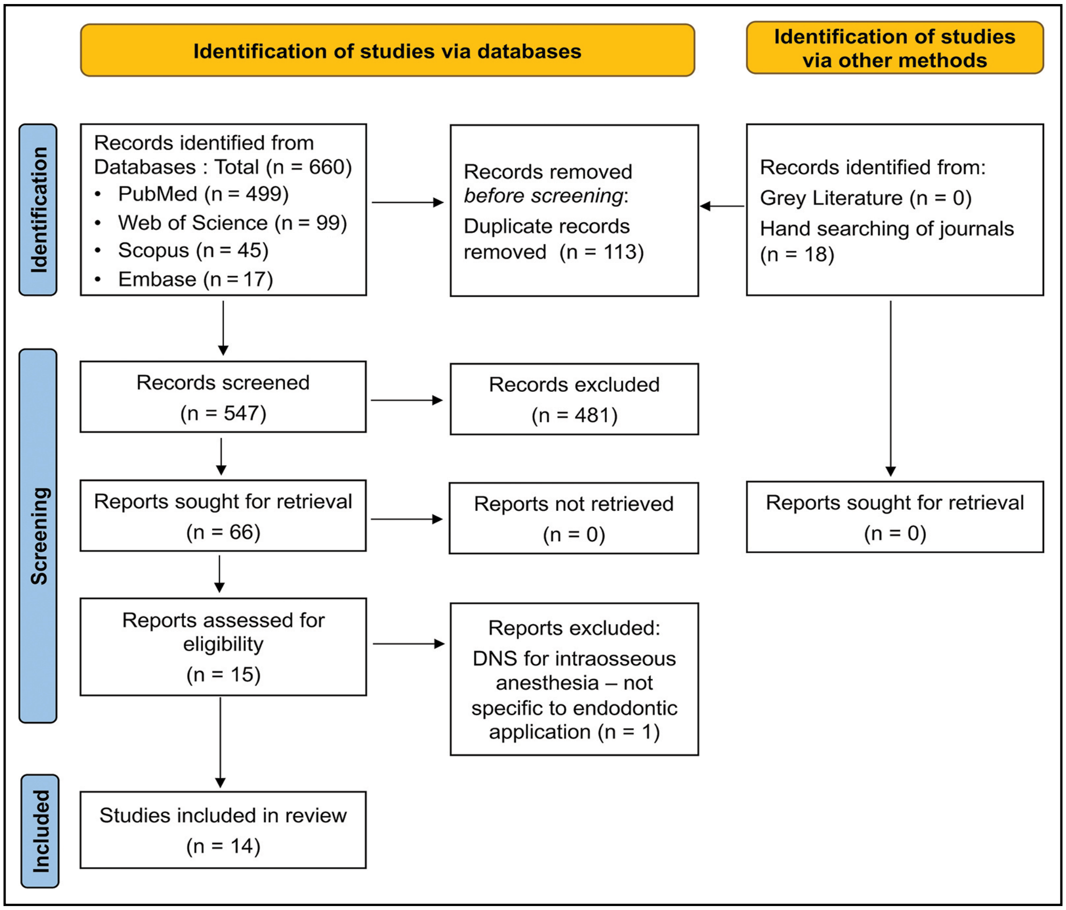

Figure 1. PRISMA 2020 search flow diagram

DNS: Dynamic Navigation System

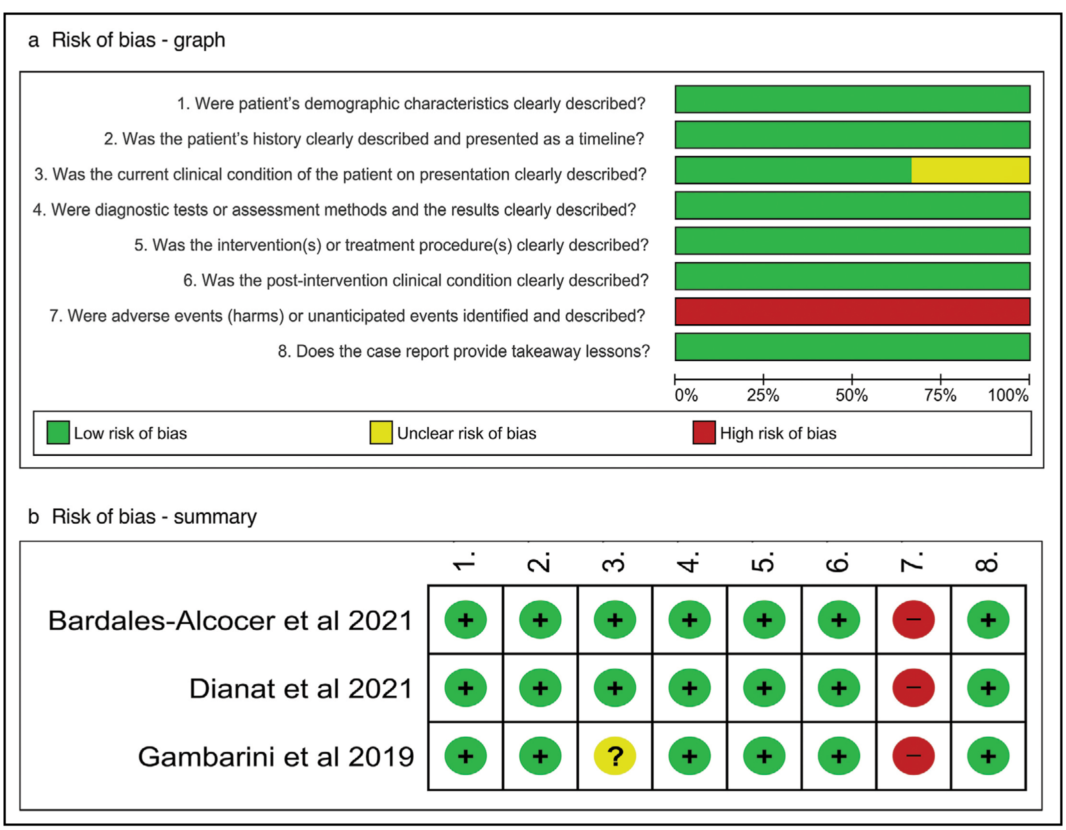

Figure 2. Risk of bias for case reports – (a) graph and (b) summary; (+) = low risk of bias; (−) = high risk of bias

Figure 3. Risk of bias for *in-vitro* studies – (a) graph and (b) summary; (+) = low risk of bias; (−) = high risk of bias

Institute (JBI) critical appraisal checklist for case reports (13) and a modified JBI critical appraisal checklist for quasi-experimental studies (non-randomized experimental) (14). One question on 'follow up' in the JBI checklist for quasi-experimental studies was not pertinent to *in-vitro* studies and eliminated. Thus, the tool was modified, with a total of eight questions to be scored. The final score of each article was calculated based on the percentage of positive answers ('yes') and was classified as having a 'high' risk of bias [score ≤49%], 'moderate' risk of bias [score ranging from 50%-69%] and 'low' risk of bias [score >70%] (15).

Data extraction

A data extraction form was created using a Microsoft Excel spreadsheet, and data was retrieved by three reviewers (A.V., R.J., D.T.) and verified by a senior endodontist (V.N.). The following data were obtained from the selected articles: (i) study characteristics: author and year of publication, type of article; (ii) methods: endodontic application, tooth type and material, sample size; (iii) intervention characteristics: DNS used, CBCT particulars (type of CBCT, voxel size, field of view, resolution), other equipment used, training of clinician; (iv) outcome: time taken, iatrogenic errors, accuracy analysis, success rate.

RESULTS

Study selection

The PRISMA 2020 search flow diagram is presented in Figure 1. A total of 678 articles were obtained from the electronic database search, grey literature and hand searching. Application of eligibility criteria and elimination of duplicates yielded 66 articles. After screening titles and abstracts, 15 articles were selected for full-text assessment. Following the full-text reading, one article was excluded (16) as it assessed DNS use for intraosseous anaesthesia delivery, which is not specific only to endodontics. Finally, 14 articles that fulfilled the eligibility criteria were included for qualitative analysis.

Study quality assessment

Methodological quality appraisal of the included articles using the JBI critical appraisal checklist for case reports is presented in Figure 2. A modified JBI critical appraisal checklist for quasi-experimental studies (*in-vitro* studies) is presented in Figure 3. All three case reports had a low risk of bias, with a mean score of 83.34% (Appendix Table 1). For *in-vitro* studies, nine had a low risk of bias, and two had a moderate risk of bias, with an average score of 84.09% (Appendix Table 2).

Study characteristics

The publication year of the included articles ranged from 2019 to 2021. There were three case reports (11, 17, 18) and eleven *in-vitro* studies (9, 10, 19-27).

Qualitative analysis

Applications/uses

Based on the uses of DNS in endodontics (Table 2), there were four articles where DNS was used for endodontic access cavity preparation and root canal location (20, 22, 23, 27), six articles for negotiation of pulp canal obliteration (PCO) (9, 10, 18, 19, 21, 26), two articles for endodontic retreatment (17, 25) and two articles for endodontic microsurgery (11, 24).

TABLE 2. Characteristics of included studies

Study characteristics and methods			Intervention characteristics			Outcome	
Author; year	Article type; Endodontic application	Type of teeth; (Sample size)	DNS; CBCT particulars	Other equipment	Training of clinician	Time taken; Iatrogenic error	Success rate
Chong et al. 2019 (10)	IV PCO	I, C, PM, M Natural teeth (29)	Navident NM	HSH and diamond bur for enamel, SSH and round stainless steel bur for dentine	NM	NM 1 (P) canal each was successfully located in 2 Mx 2nd M; access for 3rd canal (DB)- misaligned & off-target in one	26/29 teeth = all canals located
Gambarini et al. 2019 (11)	CR EMS	Mx right lateral I Natural (1)	Navident NM	Round diamond #801-018C bur (SS white) mounted on a HSH	Non experienced undergraduate student-short training	Mx left 1st M <45 min NM	Precise root localisation & apicoectomy; clinical & radiographic success at 1, 3 & 6 month follow-up.
Dianat et al. 2020 (19)	IV PCO	Mx & Md single-rooted I, C, PM Natural (60)	X-Guide Full arch - (CS 9300; Carestream LLC) at 0.09 mm resolution	Round diamond bur and HSH followed by #1 (0.8 mm) Munce bur on a SSH at 5000 RPM	Board- certified endodontist & a III year endodontic resident - calibrated on 40 teeth (20 each)	Mean of 4 min (maximum of 7 min) Gouging in 1 sample located (29/30 teeth)	Reduced angular & linear deviations; less loss of dentine: higher accuracy of DNS - 96.6% canals without perforation.
Gambarini et al. 2020 (20)	IV EAC (ultraconservative)	Mx right first M Artificial resin teeth : TrueTooth (20)	Navident OP-Maxio 300, Instrumentarium-KaVo, Biberach, Germany	2 mm initial opening with small round 1⁄4 bur (SSWhite), a precision micro endodontic bur (SSWhite) with a 0.33 mm tip &1 mm maximum diameter-at 10000 RPM (HSH)	Skilled operator	Mean of 11.5 s NM	DNS was significantly more precise, with smaller differences in angulation (4.8°) & linear deviation (0.34 mm)
Jain et al. 2020 (9)	IV PCO	Anteriors, PM, M 3D printed (84)	Navident CS 8100 3-D; Carestream Health Inc, Rochester, NY with a minimum voxel size of 75 µm	Micro endodontic (tip diameter = 0.28 mm) HSH access burs (Endoguide SSWhite): for initial access with surgical-length (tip diameter = 0.21 mm) tapered diamond carbide burs (859 FGSL; Komet)	Board-certified endodontist after undergoing training sessions of over 20 samples with DNS	57.8 s - drilling time dependent on canal orifice depth, tooth type, jaw NM	Mean 3D deviation from canal orifice was 1.3 mm - marginally higher on Mx than Md teeth. Mean 3D angular deviation was 1.7°- significantly higher in M than PM
Jain et al. 2020 (21)	IV PCO	Mx & Md central I 3D printed (40)	Navident Limited FOV CBCT-CS 8100 (Carestream Health Inc) 60 kV peak, 2 mA, 15 s, 75 µm voxel size.	HSH and surgical length #2 round bur (Coltene), an 859 FGSL bur (Komet), an EndoZ bur (Dentsply Sirona)	Second-year endodontic resident - training	136.1 s (ranging from 101.4–170.8 s) 1 unsuccessful canal location and perforation	Significantly less mean tooth substance loss for DNS (27.2 mm3 vs 40.7 mm^3); higher optimal precision -75% (centred drill path)
Zubizarreta-Macho et al. 2020 (23)	IV EAC	Md central I Natural (30)	Navident WhiteFox, Satelec, France: 105 kV peak, 8 mA, 7.20 s, FOV of 15×13	HSH and diamond bur (diameter 1.2 mm)	NM	NM Freehand - 2 missed canals & 1 perforation	Endodontic access by DNS - more accurate than Static Navigation, not statistically significant.
Pirani et al. 2020 (22)	IV EAC	2 Md M & 1 Md PM Natural (3)	ImplaNav VGi, NewTom, Verona, Italy: (110 kV, 3 mA, 0.15 mm, FOV 10×5)	Diamond bur mounted on a HSH	Undergraduate student	NM None	Reduced dentinal destruction with 100% accuracy in identifying canals

TABLE 2. Cont.

Study characteristics and methods			Intervention characteristics			Outcome	
Author; year	Article type; Endodontic application	Type of teeth; (Sample size)	DNS; CBCT particulars	Other equipment	Training of clinician	Time taken; Iatrogenic error	Success rate
Bardales-Alcocer et al. 2021 (17)	CR ERT	Mx left lateral I Natural (1)	Navident NM	HSH and Great White Z 801-014 diamond bur for zirconia; ultrasonic ED7 tip	NM	NM NM	Clinical & radiographic success at 18 month follow-up.
Dianat et al. 2021 (18)	CR PCO	Mx right first M Natural (1)	X-Guide Full arch - (CS 9300, Carestream LLC, USA) 0.120 mm resolution	#1 Munce bur	Trained, calibrated & completed 40 DNS cases before the current attempt	NM NM	Successful localisation of DB canal with clinical & radiographic success at 2 week and 6 month follow-up.
Dianat et al. 2021 (24)	IV EMS	10 I & C; 4 PM; 6 M Natural (human cadaver) (40)	X-Guide Single-arch CBCT (CS 9300; Carestream, Atlanta, USA) taken at 0.120 mm^3 voxel size	Precision drill followed by a 3.5 mm diameter tapered bone drill on a SSH at 5000 RPM	Trained and calibrated operator- completed 20 DNS cases before the current attempt	212 s 2/20 mishaps	Mean global deviations & angular deflections- significantly less in DNS compared to freehand ($p \leq 0.001$)
Janabi et al. 2021 (25)	IV ERT (fibre post removal)	Mx C and I Natural (26)	X-Guide Single arch CBCT scan (CS 93000, Carestream, Atlanta, GA) taken at 0.120 mm^3	1 (0.9 mm) & #2 #(1.1 mm) Munce Bur on a SSH at 5000 RPM	Experienced endodontist, trained and calibrated [performed 20 procedures prior]	4.03 min None	100% success for DNS: with significantly less coronal & apical deviations, angular deflection & volumetric tooth loss
Torres et al. 2021 (26)	IV PCO	Mx and Md-I, C, PM, M 3D printed (132)	Navident NewTom VGi evo (NewTom, Verona, Italy) voxel size of 0.125 mm	Round diamond bur (1 mm diameter), WG-99 LT handpiece (W&H), #2 Munce Discovery bur mounted on a WG-56 LT handpiece (W&H)	Final year dentistry student, 2 endodontic specialists with 5 & 30 years of experience- calibrated 1 week prior (28 access cavities)	NM None	93% success (156/168 canals); Mean apical deviation: 0.63 mm; Mean angular deviation: 2.81° significant difference in substance loss of Mx&Md jaw (4.2% vs 4.9%)
Connert et al. 2021 (27)	IV EAC	Mx central and lateral I, Mx C 3D printed (72)	DENACAM Accuitomo 170 (Morita Manufacturing Corp, Kyoto, Japan): voxel size 125 µm, 90 kV, 6 mA, FOV 6x6 cm	HSH (T1 Classic S, Dentsply Sirona) and cylindric diamond bur (1 mm diameter)	Two dentists with 12 and 2 years of professional experience- training NM	195 s (ranging from 135-254 s) 2 canals (1 in DNS, 1 in conventional) perforated by less experienced operator	Mean substance loss significantly lesser in DNS (10.5 mm^3) compared to freehand (29.7 mm^3)

IV: *In-vitro*, CR: Case report, PCO: Pulp canal obliteration, EMS: Endodontic microsurgery, EAC: Endodontic access cavity, ERT: Endodontic retreatment, I: Incisor, C: Canine, PM: Premolar, M: Molar, Mx: Maxillary, Md: Mandibular, DNS: Dynamic navigation system, HSH: High-speed handpiece, SSH: Slow-speed handpiece, min: Minutes, s: Seconds, MB: Mesiobuccal, DB: Distobuccal, P: Palatal, FOV: Field of view, NM: Not mentioned

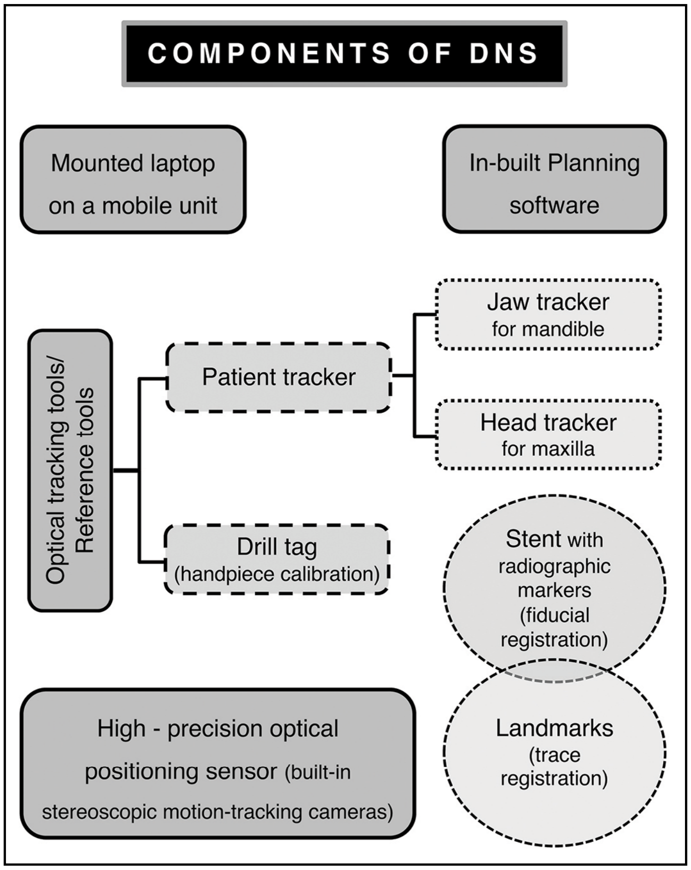

Figure 4. Components of dynamic navigation system

Endodontic access and accurate detection of root canals

All four articles that evaluated routine root canal detection accuracy using DNS for endodontic access were *in-vitro* studies (20, 22, 23, 27). Furthermore, all articles used high-speed handpieces and corresponding diamond burs for the entire access opening procedure (20, 22, 23, 27).

Three studies reported that DNS helped in more precise, predictable, accurate and safe canal location when used for different types of access cavity preparation such as routine endodontic access (23), minimally invasive or truss access (22), and ultraconservative access (20). An undergraduate student performed the procedure with 100% accuracy in one of these studies (22). In the study by Gambarini et al., (20) smaller differences in DNS-driven drill path angulation (4.8°) and deviation (0.34 mm) were recorded. The mean substance loss occurring during DNS-guided access was also found to be significantly lesser than freehand access preparation (10.5 mm^3 vs 29.7 mm^3) by Connert et al. (27), with another study confirming its superiority to freehand access (23). In addition, there was only one instance of perforation reported during DNS-assisted access by an inexperienced operator (27).

Two studies reported the time for access preparation using DNS to be 11.5 seconds (20) and 195 seconds (27). This is less than the time taken using the manual (freehand) approach for the same procedure [12.2 seconds (20) and 193 seconds (27)], although not statistically significant.

Management of pulp canal obliteration (PCO)

Among the six articles that used DNS to negotiate calcified root canals, one was a case report (18), while the other five were *in-vitro* studies (9, 10, 19, 21, 26). In the case report (18) and one *in-vitro* study (26), the authors used a Munce bur in a slow-speed handpiece for drilling. Two *in-vitro* studies had used high-speed regular and surgical length tapered diamond burs (9, 21), while the other two had used high-speed handpiece and diamond burs for entry into enamel followed by round stainless steel bur (10) or #1 Munce bur in a slow-speed handpiece (19) for cutting into dentine.

The negotiation of sclerosed canals using DNS had a success rate of 100% in two articles (9, 18), between 90 - 95% in two articles (10, 26), and above 95% in two articles (19, 21). Only a few errors, such as misaligned or off-target drilling (10), gouging (19), and unsuccessful canal location due to perforation (21), were reported. DNS was found to have higher accuracy, efficiency, precision and reliability when compared to freehand negotiation of calcified canals (19, 21).

DNS-assisted drilling was shown to have low 2-dimensional (2D) horizontal or lateral deviation ranging from 0.63 mm (26) to 0.9 mm (9), with linear deviations as low as 0.19 mm in the buccolingual direction and 0.12 mm in the mesiodistal direction (19). It also resulted in reduced angular deviations during drilling (19), ranging from 1.7° (9) to 2.81° (26), with a 3D lateral deviation of 1.3 mm (9) having been reported. Guided PCO negotiation using DNS also resulted in significantly lesser tooth substance loss (27.2 mm^3) when compared to freehand negotiation (40.7 mm^3), as reported in two studies (19, 21).

Time taken for negotiation of PCO was reported in three articles (9, 19, 21) and ranged from 57.8 seconds (9) to 240 seconds (19).

Endodontic retreatment

Bardales-Alcocer et al. (17) used the Navident DNS for successful endodontic retreatment of a symptomatic maxillary left lateral incisor, while Janabi et al. (25) found fewer deviations, tooth substance loss and no perforations when DNS-assisted fibre post removal was used during retreatment. It was possible to calibrate a high-speed handpiece (17), a slow-speed motor (25), as well as an ultrasonic unit (17) with the DNS. The mean time taken for fibre post removal using DNS was only half of that taken when the procedure was performed freehand (25).

Endodontic microsurgery

In the case report by Gambarini et al., (11) DNS aided in accurate localisation of the root, precise apicoectomy and minimally invasive osteotomy with no iatrogenic errors by a non-experienced undergraduate student. Dianat et al. (24) found that the mean 3D deviations and angular deflection were significantly reduced for DNS-assisted root-end resection, with only 2/20 procedural mishaps. The time taken reported in two separate studies were <45 minutes (11) and 212 seconds (24).

Dynamic navigation systems

The DNS used most commonly was Navident (ClaroNav, Toronto, Ontario, Canada) in eight articles (9-11, 17, 20, 21,

TABLE 3. Sequence of steps involved in the use of DNS

Step	Process involved
Scan	A preoperative CBCT scan of the jaw is taken and fed into the DNS planning software as a Digital Imaging and Communications in Medicine (DICOM) file
Plan	A drill path/ approach plan is created using the CBCT image data to determine entry points and the virtual 3D path to guide the burs during the procedure
Trace	Matching of the CBCT image data with the patient's jaw is done by registering the scan to the patient (mapping of patient's jaw onto CBCT), followed by an accuracy check once the registration is complete
a. Fiducial	A stent (customisable to each patient) with radiopaque fiducial markers serving as stable reference points is placed on the jaw, registration and a second CBCT scan is taken, which is then imported into the planning software and matched with the initial scan
b. Trace	Non-colinear landmarks (3-6) are selected in the mouth and a jaw tracker is attached to the arch; a calibrated tracer tool is slid registration along these landmarks chosen by the clinician and the system samples "point clouds" along its path which are then automatically matched with corresponding areas of the CBCT
Place	involves calibration of the handpiece (axis) and bur tip, which helps to continuously track the bur's direction/ spatial orientation, and report it to the operator in real-time on the computer screen; After this, the procedure is initiated clinically

CBCT: Cone-beam computed tomography

23, 26), followed by X-guide (X-nav technologies, LLC, Lansdale, PA, USA) in four articles (18, 19, 24, 25), ImplaNav (ImplaNav, BresMedical, Sydney, Australia) in one article (22) and DENACAM (mininavident AG, Liestal, Switzerland) in one article (27).

DNS workflow

The basic components and sequence of steps involved in DNS use are given in Figure 4 and Table 3.

DISCUSSION

The common analogy used for computer-aided dynamic navigation is the GPS-tracking system (Global Positioning System). However, to the best of our knowledge, there has been no systematic review on the applications, accuracy, advantages, and limitations of dynamic navigation in endodontics.

DNS appears to be highly beneficial in challenging clinical situations where higher accuracy and precision are required (8, 26, 28). Through this systematic review, it is evident that DNS has a broad range of applications in endodontics, such as PCO (9, 10, 18, 19, 21, 26), access cavity preparation (20, 22, 23, 27), endodontic retreatment (17, 25) and endodontic microsurgery (11, 24).

The available research on DNS applications in the field of endodontics is still limited. However, since *in-vitro* studies form the base of the evidence pyramid, following which other observational studies can be conducted, and carrying out study designs of such a nature to test DNS efficacy may be difficult, this systematic review on *in-vitro* studies is relevant.

This review qualitatively assessed fourteen articles comprising three case reports and eleven *in-vitro* studies. Quality appraisal was done using JBI critical appraisal tool for case reports and the modified JBI critical checklist for quasi-experimental studies. All three case reports and nine *in-vitro* studies had a low risk of bias, while only two *in-vitro* studies had a moderate risk of bias. However, a meta-analysis was not possible due to methodological heterogeneity of data among the included articles.

The accuracy of DNS is determined by comparing 2D and 3D deviations between the planned and prepared drill paths. Accuracy data on implant placement using DNS revealed that the mean 2D lateral deviation was 0.67 mm coronally and 0.9 mm apically, with an angular deviation of 2.50° (28). Endodontic access using DNS and high-speed drills was shown to have a mean 2D horizontal deviation of 0.9 mm, and an angular deviation of 1.7° (9). Thus, the use of DNS for endodontic applications appears to be efficient.

Iatrogenic errors during endodontic treatment can also be minimised with the aid of DNS. Among the articles included, five articles had mishaps such as misaligned off-target access (10), gouging (19), unsuccessful canal location and perforation (9, 27) and incomplete root-end resection (24). Although DNS seems to be highly beneficial in challenging endodontic situations, over-dependence on technology is undoubtedly a cause for concern. Though minimal, systematic errors may be attributed to loss of jaw tracker stability mid-treatment, loss of real-time tracking while rectifying drill path or inadequate mapping of landmarks (9, 21). Furthermore, non-systematic errors like hand tremors, inaccuracies in human perception (29), and unforced errors due to image acquisition or CBCT artefacts must also be considered (9). Jain et al. (9) has suggested a mid-treatment accuracy check followed by radiographic verification to eliminate such undesirable outcomes.

The time taken for endodontic treatment using DNS ranged from 11.5 seconds for ultraconservative access preparation (20) to <45 minutes for endodontic microsurgery (11). Compared to freehand procedures, there appears to be a significant reduction in chairside time while executing treatment using DNS (21). However, one must keep in mind the additional time involved in CBCT scanning, tracing landmarks, stent fabrication, and virtual designing.

The *in-vitro* study by Jain et al. (16) to evaluate the safety and 3D accuracy of intraosseous anaesthesia delivery using the X-Tip system (Dentsply Sirona, USA) between DNS-guided and freehand injection methods was not included in the current systematic review since this application of DNS is not specific only to endodontics. However, even this study proved the safe use of DNS, with lesser deviations and no instances of root perforation (16).

Five included articles in this review used 3D printed teeth as samples for evaluation (9, 20, 21, 26, 27). Although this ensures a high level of standardisation, inherent drawbacks like lack of anatomical landmarks and variability in drilling through resin must be kept in mind (30).

The first-generation DNS requires the fabrication of a thermoplastic stent with radiographic fiducial markers (28). In addition, the stent must be secured in the same position during scan acquisition and drill path preparation (28). If not, a guidance error may compromise accuracy (28). The new second-generation trace registration system overcomes the drawbacks of the fiducial approach by eliminating the need for a stent (9). Instead, a tracer tool is used to map anatomic landmarks on the patient's jaw with the pre-existing CBCT scan (9, 28).

Furthermore, it allows for real-time recalibration and retracing in case of inaccuracies (28). Thus, radiation exposure due to additional CBCT scans, extra cost and time considerations for stent fabrication are eliminated, enhancing chairside clinical feasibility (9, 21). Nevertheless, the DNS technology should be considered in cases of increased complexity as they facilitate the treatment and reduce the risk of iatrogenic errors.

In one article, the cost factor of the second-generation Navident was compared with static guides and stents, wherein the authors surprisingly concluded that DNS was economical (9). 3D printed static guides were introduced long before dynamic navigation in guided endodontics (31). Their fabrication involves intraoral scanning, guide designing and 3D printing, which add to the time and cost factor (31-33). Nevertheless, in this age of technology-driven dentistry, virtual planning software and 3D printing facilities are available in digital centres worldwide, which may help reduce the expenses required for static guide fabrication. In contrast, the initial cost of investing in a DNS and associated software requirements will add to the overall treatment cost. This has not been discussed in any of the included articles.

Another advantage of static guides is their ability to be used even by less experienced operators in an accurate, reproducible manner with a smaller learning curve (6, 7, 30, 32). Seven articles in this review specified operator training and calibration for DNS applications (9, 11, 18, 19, 24-26). Manual dexterity, hand-eye coordination, and technical skills are essential for DNS use (9, 19, 21). In addition, the operator must get accustomed to looking at the monitor while performing the clinical procedure. So, a steep learning curve is associated with this optically driven technology requiring training and calibration instead of static guides.

Access preparation using 3D printed static guides has proven accurate and precise (1, 7, 32). However, a slight lateral deviation was recorded clinically in around 56% of cases (1). This deviation may be due to misalignment of the scans leading to incorrect drill path and guide fabrication (1, 10). The inability to change the predefined drill path orientation with static guides can be overcome when DNS is used, as it tracks the deviation in real-time (9, 10).

A crucial part of the DNS workflow is the requirement of a full arch CBCT scan (18, 19, 24). Undeniably, CBCT involves more ionising radiation than conventional radiographs (34, 35). This being a limitation, a recent study showed that using a non-ionising radiation alternative, Magnetic Resonance Imaging (MRI), for DNS has been advocated (36).

Limitations

Meta-analysis was not feasible due to heterogeneity of data among the included articles on sample size, type of teeth, outcome measures and other methodological differences. Moreover, the included articles were either case reports or *in-vitro* studies making the available evidence low. In this sense, the extrapolation of the results must be carefully considered.

Future perspectives

Currently, there are four different DNS available for endodontic use - Navident, X-guide, ImplaNav and DENACAM. So far, there have been no studies comparing the efficacy and accuracy of these systems in endodontics, and hence future studies should consider doing the same. In this systematic review, four articles showed that inexperienced operators performed the procedure successfully while using DNS (9, 11, 22, 26). Nevertheless, a single operator could have inherently had higher clinical skill and knowledge levels. Future studies should thus consider testing DNS efficacy among multiple operators with various levels of expertise. The presently available evidence to support DNS use is only from case reports and *in-vitro* studies. Thus, as warranted by the hierarchy of evidence for translational research, clinical studies with long-term follow-ups are required in the future. Additionally, future laboratory studies testing DNS should also consider following the PRILE 2021 guidelines for uniformity in reporting (37).

CONCLUSION

DNS can be successfully applied in challenging clinical situations like pulp canal obliteration, conservative access, endodontic retreatment and endodontic microsurgery, with the advantages of being efficacious, causing fewer iatrogenic errors and taking a shorter chair time. However, the level of evidence provided in this review is low due to the included articles being either case reports or *in-vitro* studies. Future clinical studies testing the efficacy of DNS are thus required for more credible evidence.

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APPENDIX 1. JBI critical appraisal checklist for case reports

Study name	1	2	3	4	5	6	7	8	Total score %
1. Gambarini et al. 2019 (11)	Y	Y	Unclear	Y	Y	Y	N	Y	75
2. Bardales-Alcocer et al. 2021 (17)	Y	Y	Y	Y	Y	Y	N	Y	87.5
3. Dianat et al. 2021 (18)	Y	Y	Y	Y	Y	Y	N	Y	87.5

JBI: Joanna Briggs Institute

APPENDIX 2. JBI critical appraisal checklist for quasi-experimental studies (non-randomized experimental studies)

Study name	1	2	3	4	5	6	7	8	Total score
1. Chong et al. 2019 (10)	Y	N	Y	N	N	Y	Y	N	50
2. Dianat et al. 2020 (19)	Y	N	Y	Y	Y	Y	Y	Y	87.5
3. Pirani et al. 2020 (22)	Y	N	Y	N	N	Y	Y	N	50
4. Gambarini et al. 2020 (20)	Y	Y	Y	Y	Y	Y	Y	Y	100
5. Jain et al. 2020 (a) (9)	Y	Y	Y	N	Y	Y	Y	Y	87.5
6. Jain et al. 2020 (b) (21)	Y	Y	Y	Y	Y	Y	Y	Y	100
7. Zubizarreta-Macho et al. 2020 (23)	Y	Y	Y	Y	Y	Y	Y	Y	100
8. Dianat et al. 2021 (24)	Y	N	Y	Y	Y	Y	Y	Y	87.5
9. Janabi et al. 2021 (25)	Y	N	Y	Y	Y	Y	Y	Y	87.5
10. Torres et al. 2021 (26)	Y	Y	Y	N	Y	Y	Y	Y	87.5
11. Connert et al. 2021 (27)	Y	Y	Y	Y	N	Y	Y	Y	87.5

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