Review Article

Dynamic navigation in endodontics: A comprehensive literature review

Vivek Hegde, Lalita Mandke[1], Khatija Memon, Musharraf Ansari[2], S. Srilatha, Asiya Mujawar[3]

Department of Conservative Dentistry and Endodontics, M. A. Rangoonwala College of Dental Sciences and Research Center, [3]Department of Conservative Dentistry and Endodontics, Sinhgad Dental College and Hospital, Pune, [1]Department of Conservative Dentistry and Endodontics, DY Patil University School of Dentistry, [2]Department of Conservative Dentistry and Endodontics, Terna Dental College and Hospital, Navi Mumbai, Maharashtra, India

Abstract

Dynamic navigation has emerged as an innovative technology in endodontics, offering enhanced precision and efficiency compared to traditional and static navigation techniques. By integrating real-time imaging and computer-guided navigation, dynamic navigation systems (DNSs) are transforming the way endodontic procedures are performed. DNSs have demonstrated superior accuracy and efficiency in endodontic treatments, leading to improved procedural outcomes and patient satisfaction. These systems facilitate minimally invasive procedures, reduce treatment time, and enhance the overall precision of root canal treatments, apical surgeries, and retreatment cases. However, challenges such as cost, accessibility, and the learning curve for practitioners remain. Dynamic navigation represents a significant advancement in endodontics, with the potential to revolutionize clinical practice. As technology continues to evolve, further research and innovation are expected to address the current limitations and expand the applications of dynamic navigation in dental care. This review underscores the importance of adopting DNSs to improve the treatment outcomes and patient care in endodontics.

Keywords: Clinical applications; computer-assisted therapy; endodontics; navigation systems; outcome; root canal treatment

INTRODUCTION

Dynamic navigation in dentistry is a ground-breaking technology that significantly improves the precision and control of various dental procedures. This technology facilitates real-time monitoring and guiding of dental instruments, ensuring adherence to preoperative plans. Navigation in dentistry is primarily divided into three types: Freehand, static, and dynamic. Freehand navigation involves the clinician visualizing and transferring a fixed position from surgical planning to the surgical site based on anatomical landmarks derived from the diagnostic casts and radiographs. This method does not utilize a predefined path, making it challenging to direct instruments accurately[1] static navigation uses a computer tomographic-based guide, created through computer-aided design and computer-aided manufacturing or three-dimensional (3D) printing, which remains fixed during the procedure. These guides incorporate metal sleeves and require specialized drills, ensuring precise placement by keeping the guide static. Bone, mucous membrane, or teeth can sustain static surgical guides.[1]

Dynamic navigation employs optical positioning devices controlled by a computerized interface to integrate the surgical instruments with radiological images, offering real-time guidance using imported computed tomography (CT) or cone-beam CT (CBCT) datasets. This system functions similarly to GPS technology, displaying a clinical real-time interface on a screen that directs

Address for correspondence:
Dr. Asiya Mujawar,
Department of Conservative Dentistry and Endodontics, Sinhgad Dental College and Hospital, Pune, Maharashtra, India.
E-mail: drasiyamujawar91@gmail.com

Date of submission : 05.08.2024
Review completed : 10.09.2024
Date of acceptance : 06.11.2024
Published : 10.12.2024

Access this article online	
Quick Response Code:	Website: https://journals.lww.com/jcde
	DOI: 10.4103/JCDE.JCDE_551_24

How to cite this article: Hegde V, Mandke L, Memon K, Ansari M, Srilatha S, Mujawar A. Dynamic navigation in endodontics: A comprehensive literature review. J Conserv Dent Endod 2024;27:1202-10.

the operator through a preplanned path to the target location.[2] X-Guide (X-Nav Technologies), Image-guided Implantology (Image Navigation), Navident (ClaroNav), and RoboDent (RoboDent) are the examples of dynamic guidance systems for implant placement that have been developed.[1]

The introduction of Navident III/Evo has addressed various challenges, focusing on various key areas. The cart also has a static configuration, installed on a mount, which is connected to an arm affixed either to the wall or to the ceiling of the operatory [Figure 1] The camera box is equipped with the robotic Micron Tracker 4 (MT4) stereoscopic camera unlike the MT3 with the Navident II/UNO. It has two servo motors for real = time optimal detection patient's jaw and trackers with a capacity to move 175° sideways and 90° vertical. The Jaw Tracker-T (JTT [tray]) which has 3 types (1, 2, and 3) uses JTT4 with smaller optical markers than JTT3 used for UNO. The head tracker too has smaller tracking tag compared to Navident II. The tracer tool is more compact with a stainless-steel ball tip with a diameter of 1 mm and the handle/tail made of black-anodized laser-marked aluminum alloy. The drill tag is replaced with the handpiece tracker which is designed to be attached to either a high speed, surgical or peizotome handpiece. An aluminum ring attaches the handpiece to the tracker marked with optical tracking targets.

HISTORICAL ASPECT

The concept of navigation in surgery began in neurosurgery in the mid-20th century. In 1947, Spiegel *et al*. introduced the stereotactic frame, a device designed to improve the accuracy of brain surgeries by providing a reference

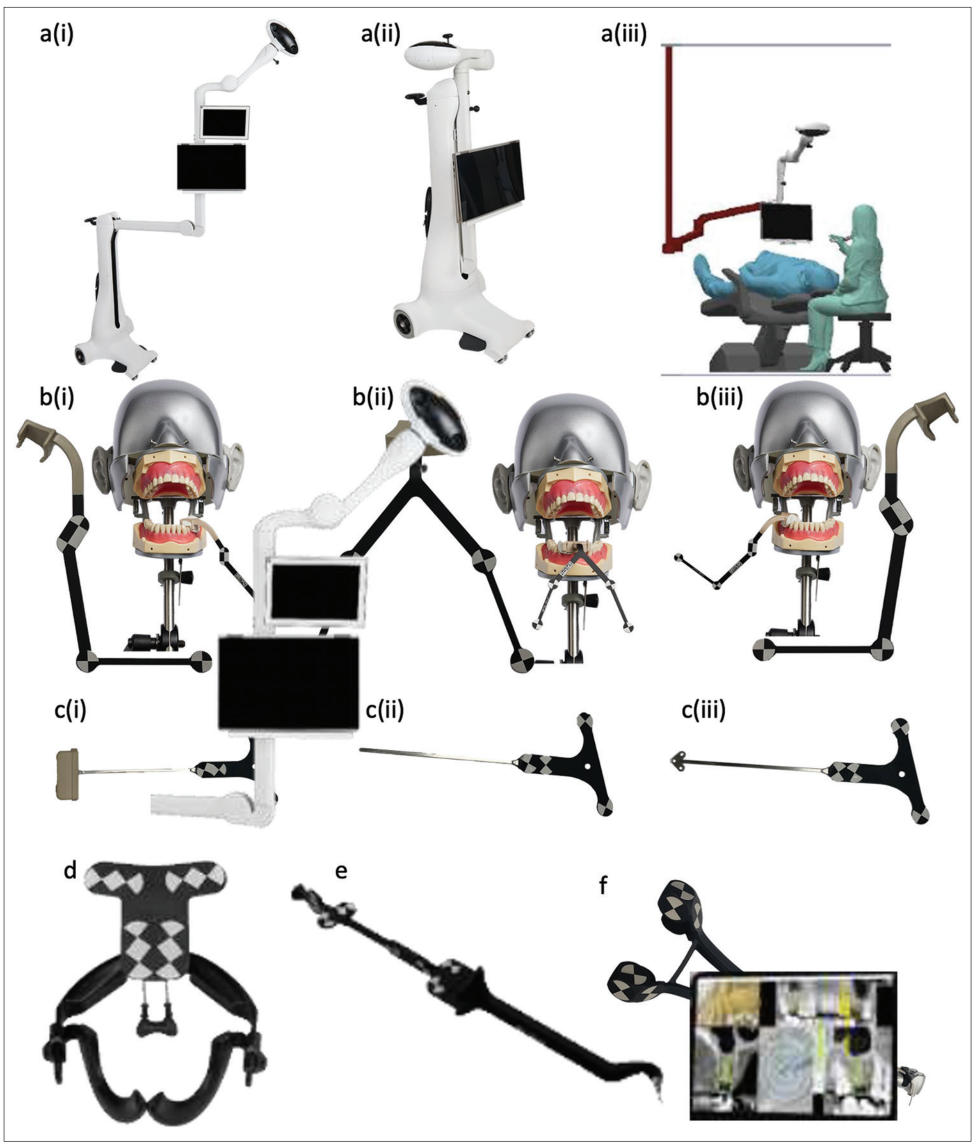

Figure 1: The parts of Navident III/EVO – (a): (i) Navident EVO open, (ii) Navident EVO closed, (iii) Navident EVO mounted, (b): (i-iii) Jaw tracer tray 1, 2, 3, (c): (i-iii) Jaw tracker C, B and U.(d): Head tracker, (e) Tracer tool 4, (f) Handpiece tracker

framework based on cranial landmarks.[3] This innovation arose from the necessity to enhance orientation within the brain's subcortical structures, which were inaccessible through traditional methods.

Over the decades, navigation systems evolved and were applied in orthopedic and ear, nose, and throat surgeries to enhance procedural precision. The integration of computer-assisted technologies allowed for more accurate and safer surgeries. Initially, static guides were used, but their rigidity limited adjustments during surgery. The development and integration of CT and CBCT imaging in the late 1990s and early 2000s enabled dynamic navigation systems (DNSs) to provide real-time, 3D visualization of the surgical site, significantly improving procedural accuracy and outcomes.[4]

The administration of dynamic navigation in dentistry first came into dental implantology where it was possible to determine the exact position of the implant drill on the reconstructed 3D image provided by CT or CBCT which resulted in minimal deviation from the preoperative planning.[5]

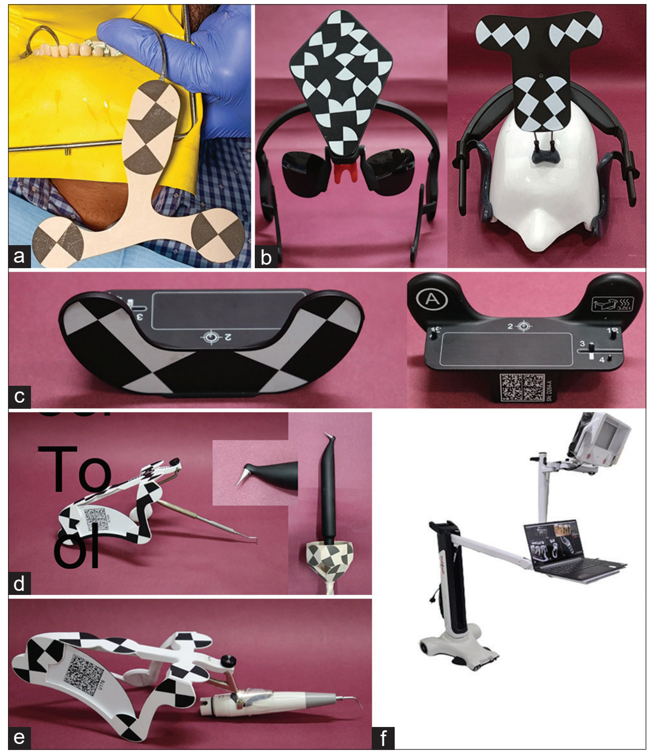

Figure 2: The parts of Navident II/UNO machine, (a) Jaw tracer, (b) Head tracer, (c) Calibrator, (d) Tracer tool, (e) Drill tag, (f) Navident UNO

PRINCIPLES OF DYNAMIC NAVIGATION IN DENTISTRY

Dynamic navigation in dentistry relies on several core principles and components to ensure procedural accuracy, efficiency, and safety. These principles guide the process from preoperative planning through the execution of the surgery.

COMPONENTS OF DYNAMIC NAVIGATION SYSTEMS

1. Motion tracking camera: Tracks the positions of dental instruments and the patient's jaw in real-time
2. Head tracker or jaw tracker: Devices attached to the patient's head or jaw to provide reference points for the navigation system
3. Tracer tool or drill tag: Tools used to calibrate and align the navigation system with the patient's anatomy
4. Handpiece attachment: An accessory connected to the dental handpiece, allowing the navigation system to track its position
5. Mounted laptop with specialized software: The central interface where the navigation system processes real-time data and provides guidance [Figure 2].

PROCEDURAL STEPS

1. Plan: The procedure begins by importing the patient's CBCT dataset into the dynamic navigation software, allowing for a 3D analysis of the patient's anatomy. This software offers various views, including panoramic, 3D reconstruction, axial, bucco-lingual, and mesio-distal sections, aiding comprehensive treatment planning
2. Trace: Securely attach the jaw or head tracker to the patient. Use a tracer tool to match the CBCT data with the patient's actual jaw by tracing visible landmarks, establishing fixed registration points. Perform an accuracy check to ensure correlation between the on-screen position and the actual teeth
3. Place: Calibrate the drill by attaching a drill tag to the handpiece. The drill axis and drill tip are calibrated and setting the drill axis and tip. The navigation software continuously tracks the position of the drill, guiding the clinician toward the target area. Real-time tracking and feedback on the navigation screen allow for precise control and adjustments during the procedure.

LITERATURE REVIEW

The relevant literature regarding dynamic navigation was searched by electronic databases such as PubMed, Google Scholar, and web of science. *In vitro* studies, case reports, and clinical trials were included. Non-English articles, nonpeer reviewed articles, and studies that involve dynamic navigation but are not specifically focused on endodontic procedures were excluded. The articles were screened using the keywords such as endodontics, dynamic navigation, calcified canals, outcome, angle of deviation, and microsurgery. Articles published in the English language were included in the literature review [Table 1].

APPLICATIONS IN ENDODONTICS

Guided endodontic access

Peri-cervical dentin (PCD) is the dentin near the alveolar crest which is very crucial for long-term survival of the tooth as it provides resistance to fracture. Thus, preparing a conservative access cavity is important for the preservation of PCD. However, there are some cases which makes conservative access cavity preparation difficult and leads to loss of precious dentin such as pulp canal obliteration and dens invaginatus/evaginatus.[28] DNS has been recently used in such cases to create a conservative access cavity preparation without the limitations of static-guided endodontics [Table 2].[6-8,32] The navigation software exactly shows the location of the tip of the bur in real time, guiding the operator to the predetermined site to locate the canals in calcified cases and cases with multiple or unusual anatomy making the access cavity preparation faster and more accurate [Table 2].[9-11,24] Dens invaginatus/evaginatus are developmental malformations which require several accurate and conservative access cavities to locate individual canal, DNS can be particularly useful in such cases.[29,30] High-speed handpieces with precision micro-endodontic burs are used with the navigation system which efficiently penetrates the enamel and maintains a minimally invasive, straight-line, and apically extended access cavity preparation thus, conserving the PCD and prolonging the intraoral life of the tooth.[8] Several *in vitro* studies comparing DNS to freehand access opening have concluded that DNS helps in achieving ultraconservative access cavities, minimized the risk of iatrogenic tooth substance loss, and takes less procedural time when compared to conventional freehand technique.[6,10]

Table 1: Description of studies included in this literature review

In vitro studies					
Endodontic access cavity preparation					
Author	Year	DNS	Specimen used	Outcome measure	Bur used
Chong *et al*.[1]	2019	Navident (ClaroNav)	Human extracted teeth	Root canal location Number of canals located	Diamond burs and round stainless-steel burs (Hager and Meisenger)
Zubizarreta-Macho *et al*.[2]	2020	Navident (ClaroNav)	Human extracted teeth	Deviation angle Horizontal deviation (Deviations were evaluated in axial, sagittal, and coronal views)	Diamond bur surface (Reference: 882 314 012, Komet Medical, Lemgo, Germany)
Gambarini *et al*.[6]	2020	Navident (ClaroNav)	Radiopaque artificial teeth replicas (True Tooth Replica #3-001, DE Labs, Santa Barbara, USA)	Location of the occlusal starting point Position of the access cavity at the orifice level Greater distance between the planned and real endodontic access cavity in terms of precision (position and angulation)	Small round ¼ bur (SSWhite, Lakewood, NJ, USA) Precision micro endodontic bur (Endo Guide EG1a, SSWhite)
Dianat *et al*.[7]	2020	X-guide system (X-Nav Technologies)	Human extracted teeth with PCO in the cadaver jaw	Preparation time Linear deviation Angular deviation Reduced dentin thickness Number of unsuccessful attempts Procedural errors	Enamel- round diamond bur Dentin-size #1 (0.8 mm) Munce bur (CJM Engineering Inc, Ojai, CA)
Jain *et al*.[8]	2020	Navident (ClaroNav)	3D printed jaw models with simulated calcifications. (TrueTooth Replica #3-001, DELabs, Santa Barbara, USA)	Preparation time 2D discrepancy (horizontal, vertical, and apical deviation) 3D discrepancy (entry and angular angulation deviation)	Precision micro-endodontic burs (Endoguide EG3; SSWhite, Lakewood, NJ) Surgical length (tip tapered diamond carbide burs (859 FGSL; Komet USA, Rockhill, SC)
Jain *et al*.[9]	2020	Navident (ClaroNav)	3D printed teeth with simulated calcifications	Total substance loss Treatment duration Qualitative precision	Surgical length #2 round bur (Coltene, Altstätten, Switzerland) 859 FGSL bur (Komet USA, Rock Hill, SC) EndoZ bur (Dentsply Sirona, York, PA)
Connert *et al*.[10]	2021	Denacam system (Mininavident)	3D printed teeth	Mean tooth substance loss Time required for access cavity	A standard cylindrical diamond bur (Intensiv SA, Montagnola, Switzerland)
Huth *et al*.[11]	2024	Denacam system (Mininavident AG, Liestal, Switzerland)	3D printed replica of calcified extracted teeth	Angular deviation at bur base and tip Substance loss Time required for canal localization	Virtual endodontic bur (Spiralbur Endo, Reference: 0.27.28.B044.051, Steco-system-technik GmbH and Co. KG, Hamburg, Germany; diameter 1 mm, working length 21 mm)

3D: Three-dimensional, 2D: Three-dimensional, DNS: Dynamic navigation system, PCO: Pulp canal obliteration

Table 2: Endodontic microsurgery

Author	Year	Specimen	DNS	Outcome measure
Dianat *et al.*[12]	2021	Cadaver	Navident (ClaroNav)	Linear deviation Angular deflection Number of mishaps
Aldahmash *et al.*[13]	2022	Cadaver	X-guide system (X- Nav Technologies)	Viability of root end cavity preparation Root end fill
Martinho *et al.*[14]	2022	Cadaver	X-guide system (X- Nav Technologies)	3D virtual deviations Angular deflection Number of mishaps
Tang and Jiang[15]	2023	3D printed jaw models	DCARER (Suzhou, China)	3D deviation 2D deviation Safety of the resections Experience of operator
Wang *et al.*[16]	2023	3D printed jaw models	DHC-ENDO1	Influence of FOV Voxel size on the accuracy of dynamic navigation
Wang *et al.*[17]	2023	3D printed jaw models	DHC-ENDO1	Platform deviation End deviation Angular deviation Resection angle Resection length deviation
Martinho *et al.*[18]	2023	3D printed jaw models	X-guide system (X- Nav Technologies)	3D virtual deviations Angular deflection Number of mishaps Root end resection time Osteotomy time
Liu *et al.*[19]	2024	3D printed maxillary anterior teeth	DCARER	Length deviation Angle deviations

FOV: Field of view, 2D: Two-dimensional, 3D: Three-dimensional, DNS: Dynamic navigation system

Table 3: Endodontic microsurgery

		Case reports			
Author	Year	Type of navigation system	Tooth of interest	Treatment performed	Bur used for osteotomy
Gambarini *et al.*[22]	2019	Navident (ClaroNav)	12	Apicoectomy	Round Revelation Diamond #801-018C bur (SSWhite, Lakewood, NJ)
Lu *et al.*[23]	2022	X-guide system (X-Nav Technologies)	36	Root end resection	Trephine bur

Table 4: Postremoval

Author	Year	Specimen	Type of navigation system	Outcome measure
Janabi *et al.*[20]	2021	Extracted teeth	X-guide system (X-Nav Technologies)	Global coronal deviations Global apical deviations Angular deflections Operating time Number of mishaps
Martinho *et al.*[21]	2024	Extracted teeth	X-guide system (X-Nav Technologies)	Global coronal deviations Global apical deviations Angular deflections Operating time Number of mishaps

Endodontic microsurgery

Endodontic surgery is indicated after failure of nonsurgical endodontic treatment and/or retreatment in cases of persistent apical periodontitis. Evidence-based literature states that, endodontic microsurgery (EMS) has a high success rate of 94% as a predictable and dependable treatment option for chronic apical periodontitis.[31] Preparing a minimally invasive bone cavity with sufficient room for an accurate apicoectomy, retrograde filling and curettage of the lesion is one of the primary challenges in surgical endodontics.

Studies have reported use of DNS endodontic surgery resulting in a minimally invasive osteotomy site, exact localization of the root, precise root end resection with a 10° bevel angle due precise direction of the bur in 3 dimensions thereby, reducing the hazard of iatrogenic error even for a less experienced operator.[11-19] Unintentional iatrogenic damage to nearby anatomic structures are avoided with DNS due to its real time 3D visualization of anatomic structures on the screen. Another advantage of EMS using DNS is a flapless surgery and small targeted osteotomy site which eventually promotes postoperative healing and reduces patient discomfort [Table 3].[22,23]

Endodontic retreatment with postremoval

Persistence of intra- and extraradicular bacteria is the cause of primary endodontic treatment failure. Such a tooth requires endodontic retreatment for optimum cleaning and shaping, disinfection and 3D obturation of the root canal system.[33] However, tooth restored with posts possesses additional challenges during retreatment due to possible chances of iatrogenic errors during postremoval such as loss of adjacent tooth structure during postremoval, formation of microcracks and

Table 5: Endodontic retreatment/postremoval

Author	Year	Clinical scenario	Type of navigation system	Tooth of interest	Bur used
Bardales-Alcocer *et al.*[27]	2021	Retreatment through zirconia crown and postremoval	Navident (ClaroNav)	22	Great White Z GWZ 801-014 diamond bur for zirconia (SS White, Lakewood, NJ) ED 7 ultrasound tip for postremoval

Table 6: Endodontic access cavity

Author	Year	Clinical scenario	Type of navigation system	Tooth of interest	Bur used
Nahmias[24]	2019	PCC	Navident (ClaroNav)	12	31 mm Munce discovery bur (CJM Engineering Tech, CA, USA)
Dianat *et al.*[25]	2021	PCC	X-guide system (X-Nav Technologies)	16	Munce bur (CJM engineering Inc., Ojai, CA, USA)
Durga Bhavani *et al.*[26]	2023	PCC	Navident (ClaroNav)	11	A size #1 Munce bur 0.5 mm diameter

PCC: Pulp canal calcification

subsequent root fracture, deviation from root apex and root perforation. Conservative postremoval is a technique sensitive procedure which needs operator experience, magnification in the form of dental loupes or dental operating microscope and ultrasonics.[34] DNS has recently been investigated as an aid in real time postremoval where the position and angulation of the tip of the instrument can be visualized and intraprocedural alteration of drill path can be done unlike static guides, if required [Table 4].[20,21] Bardales-Alcocer *et al*. performed nonsurgical retreatment through zirconium bridge and fiber post using DNS and advocated that DNS helps in minimally invasive postremoval with reduced risk of iatrogenic errors [Table 5].[27]

Foreign body removal

Computer assisted dynamic navigation has proved itself useful for the removal of foreign body such as broken needles, dental fragments or projections, metal balls as well as bullets. It is an ideal and valuable treatment modality with high degree of intraoperative accuracy used to target the foreign body. Preoperative planning can be done, and removal of the foreign object can be achieved with minimal access in comparatively less time.[35,36]

Intraosseous anaesthesia

A fundamental prerequisite for endodontic treatment in dentistry is achieving substantial pulpal anaesthesia. Not only is it advantageous for the patient to have profound pulpal anaesthesia during the root canal procedure, but it also relieves the dentist from anxiety over the patient's responses or abrupt movements during therapy. It is difficult to achieve significant amount of anesthesia in certain condition especially "hot tooth" cases. Intraosseous injections are supplementary injections with a high success rate advocated along with inferior alveolar nerve block to tackle such cases. The practitioner directly injects local anaesthetic solutions into the cancellous bone surrounding the afflicted tooth without causing iatrogenic errors like perforating the root of the tooth, inadequate perforation of cortical plate and separation or fracture of delivery tip.[37] Jain *et al*. presented a novel method for intraosseous anaesthesia utilizing computer aided DNS where the position and angulation of the tip can be controlled for precise perforation of cortical plate and delivery of the anesthetic solution into the cancellous bone without damaging the adjacent structures.[38]

CHALLENGES

Dynamic navigation in endodontics presents a promising frontier for enhancing procedural precision and patient outcomes. However, its implementation is not devoid of challenges. Technological constraints, operator proficiency, patient-specific variations, cost considerations, integration into clinical workflows, and the need for validation and standardization are the critical hurdles to overcome. Technological limitations encompass deficiencies in imaging resolution, tracking accuracy, and software algorithms, which may compromise the precision of root canal access and instrumentation guidance.[1] Operator proficiency plays a crucial role in navigating these systems effectively. Dentists must undergo specialized training to interpret navigation data and integrate navigational guidance with traditional endodontic techniques to avoid procedural errors.[39,40] Patient-specific factors, such as anatomical variations in root canal morphology, curvature, and calcification, pose significant challenges to dynamic navigation. Adaptation to individual differences in patient anatomy and real-time adjustments during the procedure are necessary for accurate instrument placement and negotiation. Moreover, patient movement and anatomical changes further complicate navigation and necessitate careful management.[41] Cost considerations are another barrier to widespread adoption. DNSs require substantial investment in equipment, software, and maintenance. Limited reimbursement policies and insurance coverage may further hinder accessibility to this technology in dental practices. Integration into clinical workflows also presents logistical challenges, requiring additional time for preoperative planning and intraoperative navigation, potentially lengthening treatment duration validation and standardization are essential for ensuring the efficacy and safety of dynamic navigation in endodontics.[42] Evidence-based guidelines and long-term studies are needed to assess the durability and success rates of navigated endodontic treatments compared to conventional approaches. Collaboration between dental professionals, technology developers, and regulatory bodies is imperative to overcome these challenges and advance the integration of navigation technology into routine endodontic practice.

FUTURE DIRECTIONS

The advancement of dynamic navigation in endodontics heralds a transformative era, offering avenues for innovation and progress. However, realizing its potential requires addressing various challenges and exploring future directions. Key areas of focus include:

- Technological advancements: Continued research and development in navigation systems are crucial for overcoming current limitations and enhancing precision in endodontic procedures. Integrating artificial intelligence (AI) algorithms can optimize navigation guidance in real-time, improving decision-making, and treatment outcomes
- Visualization technologies: Augmented reality (AR) and virtual reality (VR) integration can revolutionize the visualization of patient anatomy during endodontic procedures. AR overlays and VR simulations offer immersive environments for enhanced guidance and training, facilitating intuitive instrument navigation
- Portable solutions: Miniaturization and portability of navigation systems enable their use in diverse clinical settings, including remote or mobile dental clinics. Compact devices enhance accessibility and intraoperative navigation during challenging procedures
- Interdisciplinary collaboration: Collaboration between endodontists, engineers, computer scientists, and other experts fosters innovation in navigation technology. Insights from robotics, imaging technology, and materials science can drive the development of tailored navigation solutions
- Clinical validation: Rigorous clinical validation and adoption of DNSs are essential for their integration into routine practice. Large-scale trials and systematic reviews evaluate the efficacy, safety, and cost-effectiveness of navigated procedures compared to conventional approaches.[43]

DISCUSSION

DNS represent a transformative approach in endodontic treatment, offering enhanced precision and safety, especially in complex clinical scenarios such as calcified canals and irregular tooth morphology [Table 6].[24-26] The technology's ability to provide real-time, 3D guidance allows for adjustments during the procedure, significantly improving treatment outcomes compared to traditional methods. One of the most critical aspects of DNS is its ability to enhance procedural accuracy, as highlighted by multiple studies.[1,2,6,7,9-13,17,19,20] Chong *et al*.[1] demonstrated that dynamic navigation significantly reduces apical deviation in molar endodontics, a key factor in preventing treatment failures due to under-or over-preparation of root canals. Similarly, Gambarini *et al*. emphasized the system's capability to minimize the risk of perforation, a complication that is more common when using freehand techniques.[6] This real-time feedback allows clinicians to correct trajectories mid-procedure, a flexibility that static guidance systems lack, as noted by Zubizarreta-Macho *et al*.[2] Their study further underscored the superiority of DNS in accessing calcified canals, where small deviations could lead to catastrophic outcomes like instrument fractures or perforations.[2] However, despite the precision that DNS offers, its clinical implementation does come with challenges. Dianat *et al*. pointed out that while experienced endodontists can quickly adapt to the technology, it requires a significant learning curve for less-experienced practitioners.[7,12] The need for familiarity with both the hardware and software, combined with the inherent complexity of navigation, means that extensive training is necessary before clinicians can fully exploit the system's potential. This was further supported by Aldahmash *et al*., who emphasized that reducing procedural time while maintaining accuracy depends heavily on repeated use and practice with the system.[13] In addition to enhancing accuracy, dynamic navigation has been associated with improved clinical outcomes. Jain *et al*.[8,9] observed that DNS not only increases precision but also lowers the incidence of postoperative complications. This finding aligns with that of Nahmias *et al*.[24] who noted that DNS significantly reduces the risk of iatrogenic damage, particularly in cases with complex canal anatomy.[9] By allowing real-time adjustments, DNS minimizes the unnecessary removal of tooth structure, preserving vital dentin while reducing the risk of perforation, especially in cases with narrow or curved canals. Moreover, Martinho *et al*. evaluated DNS in clinical settings and found that it led to reduced treatment times, particularly in cases involving calcified canals.[14] They noted that the precision provided by DNS shortened procedural duration by reducing the need for trial and error during access cavity preparation. However, the authors also highlighted the high initial cost of implementing DNS in practice, a barrier echoed by Bardales-Alcocer *et al*.,[27] who pointed out that the technology's expense might limit its widespread adoption, especially in smaller dental practices.[27] The cost-to-benefit ratio remains a critical consideration for clinicians, particularly in regions where access to high-end technology is limited. The safety profile of DNS has been another area of focus in recent research.

Connert *et al*. and Huth *et al*. both reported that DNS is associated with higher success rates in treating teeth with calcified in their study which included 3D printed models.[10,11] They found that by allowing clinicians to navigate such cases with precision, DNS minimized the likelihood of procedural errors, enhancing overall treatment outcomes. In these challenging cases, DNS not only aids in reducing the risk of complications by ensuring the integrity of the canal structure is maintained. Looking toward the future, there is growing interest in integrating DNS with AI to further enhance its capabilities. Durga Bhavani *et al*. proposed that AI-driven dynamic navigation could provide real-time decision support, helping clinicians anticipate challenges and make informed adjustments during the procedure.[26] This integration could potentially reduce the learning curve for less-experienced practitioners, making the technology more accessible. Similarly, Wang *et al*. and Liu *et al*. highlighted the importance of incorporating advanced 3D imaging techniques into DNSs, particularly for EMS.[16,17,19] As precision is paramount in scaffolding and tissue regeneration, DNS could play a critical role in enhancing the outcomes in these cutting-edge therapies. Several studies, including those by Janabi *et al*., Tang and Jiang, also point to the potential for DNS to become more cost-effective as the technology matures.[15,20] By improving software integration and reducing hardware costs, it is expected that DNS will become more accessible to a wider range of practitioners, further expanding its utility beyond high-end specialist clinics to general dental practices.

CONCLUSION

Dynamic navigation represents a ground-breaking advancement in endodontics, offering a new dimension of precision, efficiency, and predictability in root canal procedures. Despite facing challenges such as technological limitations, operator proficiency, and cost considerations, the future of dynamic navigation is promising. With on-going advancements in AI integration, visualization technologies, portable solutions, interdisciplinary collaboration, and clinical validation, dynamic navigation is poised to revolutionize endodontic practice. By embracing these innovations and addressing existing barriers, clinicians can enhance the patient care and outcomes.

Disclosure statement

This article is a part of the research work conducted for fulfilment of the requirements for PhD degree.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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