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Retreatment and aesthetic restoration of maxillary incisor with calcified root canal using a dynamic navigation system: a case report

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Abstract

Background Pulp canal occlusion (PCO) increases the difficulty of root canal treatment as well as tooth preservation and restoration. This is the first case report of successful localization of a calcified root canal under the guidance of a dynamic navigation system (DNS) for complete root canal retreatment and aesthetic restoration after a failed attempt to locate the calcified root canal with a traditional dental operating microscope (DOM).

Case presentation The patient was scheduled for root canal treatment for a labially inclined maxillary central incisor and post-core crown restoration with resin veneers in another hospital, but the calcified root canal could not be located with a microscope, so the patient was referred to our department. Root canal retreatment was planned for tooth #8, and the calcified root canal of tooth #9 was planned to be located and dredged under the guidance of a DNS. We used a DNS for successful positioning and to complete the root canal retreatment operation in the following 4 steps: preoperative CBCT imaging, preoperative plan design, calibration and registration, and real-time dynamic navigation. Three months later, teeth #8 and #9 presented no clinical symptoms, after which the fiber post-cores and zirconia all-ceramic crown restorations were completed. At the 12-month follow-up visit, the patient continued to be symptomfree, and satisfied with the final aesthetic restoration.

Conclusions This case report suggests that DNS may be a promising technique with high accuracy and effectiveness to reduce the risk of iatrogenic errors and provide maximal preservation of dentin, when the traditional treatment of calcified root canals approaches failure (lateral perforation).

Keywords Pulp canal obliteration, Calcified root canal, Dynamic navigation system, Guided endodontics

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Background

Although the specific pathogenesis of pulp canal obliteration (PCO) remains unclear, the potential causes include trauma [1], caries, restorations [2], vital pulp therapy [3], orthodontic treatment [4], physiological changes in elderly patients [5], and the use of statin drugs [6]. Histological samples from teeth with PCO typically show narrow root canals [7]. Accessing narrow and calcified root canals is challenging due to the increased risk of iatrogenic complications such as perforation, alterations in canal geometry, and loss of dental hard tissues, even for experienced clinicians [8–10].

The utilization of dental operating microscope (DOM), ultrasonic tips, long shank burs, and cone-beam computed tomography (CBCT) imaging for magnification and illumination can facilitate the determination of the position and direction of partially obstructed root canals, aiding in root canal pathway planning [11, 12]. Despite these tools, accessing and preparing calcified root canals remains time-consuming and difficult [13], potentially leading to excessive removal of the tooth structure [8].

Guided endodontics is a novel approach intended to prevent iatrogenic damage and involve the use of computer-assisted static navigation guides and dynamic navigation system (DNS) [14]. Static navigation guides involve the use of manufactured templates created on the basis of CBCT data and guiding dental drills to facilitate precise but fast and conservative root canal treatment [15–17]. However, this approach is limited in that it is only suitable for straight or slightly curved portions of roots, requires extensive planning, and is incompatible with water cooling. Fabricating guides are expensive and time-consuming to construct, and implementation in limited space in the posterior dental region presents challenges [18]. Furthermore, modifications during the operation are not feasible, leading to impracticalities in the case of mishaps [19].

The DNS allows virtual planning of the operation on the basis of patient CBCT data. Optical and motion tracking of operating instruments and oral specific mark point registration [8] allow real-time, visual guidance [14, 20] during both surgical and nonsurgical treatments [11, 21–24]. Recent in vitro studies of natural tooth models suggest that DNS is more accurate and effective in locating root canals in calcified human teeth and in reducing the extent of tooth structure removal than the freehand technique is, and that DNS shortens the operative duration, thus helping clinicians avoid catastrophic accidents [19, 25]. This is the first case report of successful localization of the calcified root canal under the guidance of DNS for complete root canal retreatment and aesthetic restoration after a failed attempt to locate the calcified root canal with a traditional DOM.

The patient was scheduled to undergo root canal retreatment for a labially inclined maxillary central incisor and post-core crown restoration with resin veneers at another hospital, but the calcified root could not be located with a microscope, so the patient was referred to our department. We used DNS for successful positioning and to complete both the root canal retreatment operation and the final aesthetic restoration.

Case presentation

A 43-year-old male patient was referred to the endodontic department at the First Medical Center, Chinese PLA General Hospital, for endodontic retreatment of a calcified root canal in a maxillary central incisor in April 2023.

The patient had undergone root canal treatment and resin veneer restoration of the two maxillary central incisors at another hospital several years prior, and the specific treatment was unknown. A portion of the resin veneer had fell off, which affected the appearance and required aesthetic restoration. One-month prior, the patient underwent root canal retreatment of the left upper central incisor at another hospital. During the treatment, the surgeon noticed that the root canal was calcified and obstructed and decided to stop the treatment.

The labial side of teeth #8 and #9 were resin veneers (Fig. 1a), and the lingual side of teeth #8 and #9 was tooth-coloured fillings, which were partially missing (Fig. 1b). Both teeth #8 and #9 are labial inclinations (Fig. 1c). There was no discomfort on probing or percussion, no loosening, and no abnormalities in the gums. The periapical radiograph revealed a large high-density shadow in the coronal region of teeth #8 and #9, an inadequate and apical underfilling shadow in the root canal of tooth #8, and no obvious root canal in tooth #9 (Fig. 1d). CBCT images revealed complete calcification of the root canal in tooth #9, and a small low-density shadow in 1/3 of the labial and mesial apical roots of this tooth, as well as a drill path deviating to the labial side near the labial root surface from the pulp cavity to the upper middle part of the root in the sagittal view (Fig. 1e).

Clinical diagnosis

1. Tooth #8 was diagnosed with a tooth defect and required post-root canal treatment and underfilling.
2. Tooth #9 was diagnosed with a tooth defect, pulp canal obliteration (PCO) and chronic apical periodontitis.

Treatment options

1. Tooth #8 was scheduled for root canal retreatment.

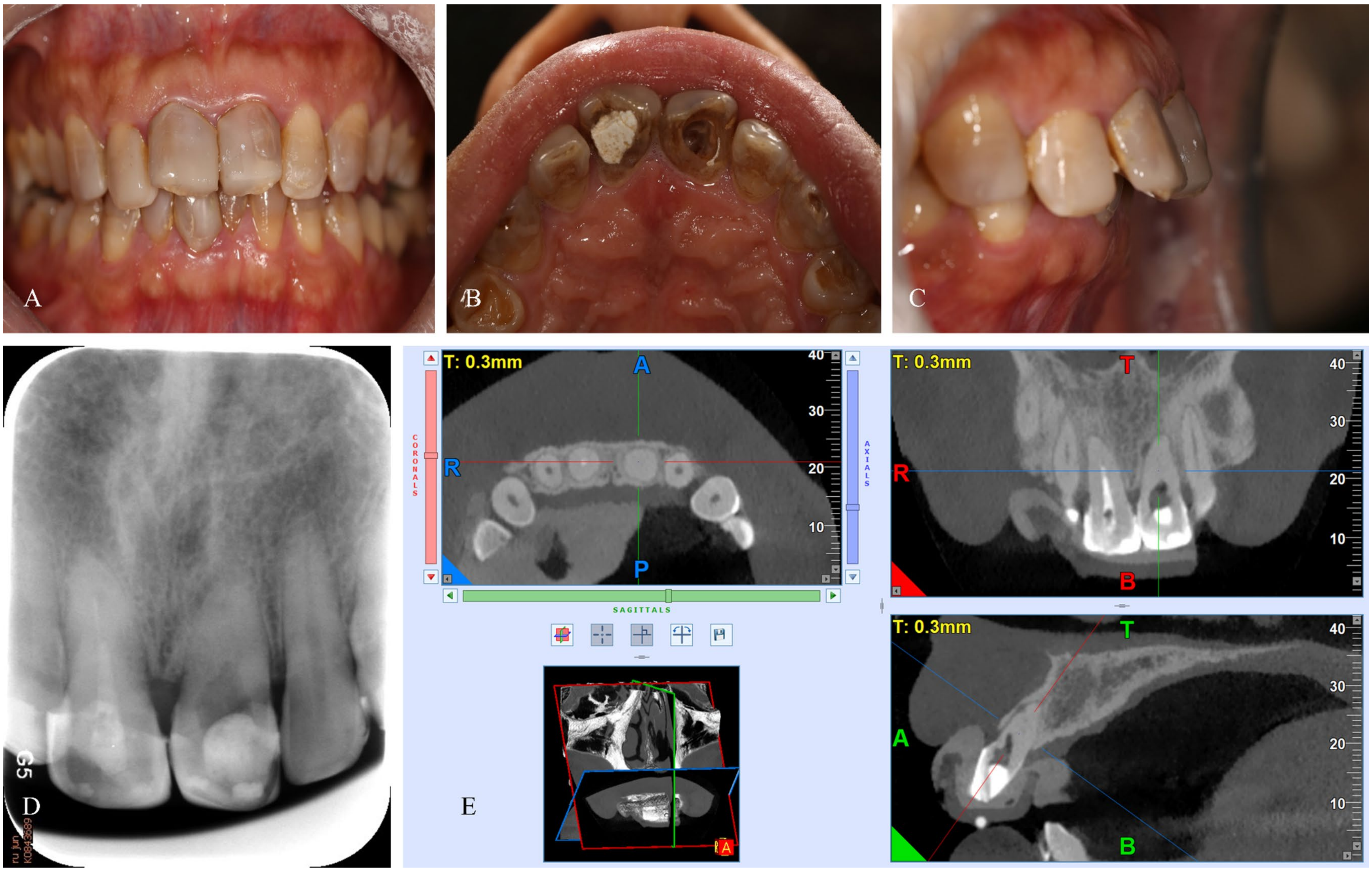

Fig. 1 Clinical examinations and radiographic imaging of patients at initial diagnosis. **A** The labial sides of teeth #8 and #9 are resin veneers; **B** The lingual sides of teeth #8 and #9 are tooth-coloured fillings, which partially fall off; **C** Labial inclination: Teeth #8 and #9; **D** The periapical radiograph shows that the root canal of tooth #8 has an inadequate and apical underfilling shadow, whereas no obvious root canal image is observed in tooth #9; **E** The CBCT images show a low-density shadow in the upper 1/3 and complete calcification in the lower 2/3 of the root canal in tooth #9. One-third of the labial and mesial apical root of tooth #9 has a small low-density shadow, and the drill path deviates to the labial side near the labial root surface from the pulp cavity to the upper middle part of the root

2. Tooth #9 was scheduled for root canal retreatment, and the calcified root canal was located and dredged under the guidance of DNS.
3. Aesthetic restoration was performed, and the anterior teeth were retracted to improve labial inclination for teeth #8 and #9.

Informed consent

The treatment protocol was approved by the Ethics Committee of the First Medical Center of PLA General Hospital (No. S2023-138-01). Patients were received detailed information about the procedures and risks and signed consent forms before treatment.

Process of treatment

For the application of dynamic navigation, the following 4 steps should be followed:

Preoperative CBCT imaging Silicone rubber impression material was used to fix a U-shaped tube in the surgical area of the patient's left upper anterior teeth before treatment. The patient wore the U-shaped tube for CBCT scanning (NewTom VGi, Verona, Italy) with the following parameters: 110 kVp, 3.0 mA, 8×8 cm field-of-view, and 0.3 mm voxel size. Digital imaging and communications in medicine (DICOM) data were obtained, and the acquired data were imported into an oral dynamic navigation system software (DCARER, Suzhou, China).

Preoperative plan design Using the DNS software, and according to the operation steps to determine the drill needle used during the treatment (Fig. 2e) and the three-dimensional direction. The approach was determined according to the principle of centralization, and the initial calcification position was connected to the long axis of tooth #9 in a straight line to ensure the thickness of the dentin on the sidewall of the root canal and avoid lateral perforation. Microadjustments were made in the cross-sectional, sagittal, and coronal planes on the three-dimensional CBCT images (Fig. 2a-d).

Calibration and registration A round bur was used to contact the pit on a reference plate at different angles for calibration (Fig. 2f) to determine the relative spatial positions of the handpiece wings and the reference plate. The reference plate was affixed to the left side of the operative area on the same jaw using self-coagulating resin. The registration device, a U-shaped tube, was reset to the operative dentition, and a round bur was used to select 6 registration pits and complete the registration process. After correction and registration, the spatial position between the medical image, the target tooth and the surgical instruments is calculated to guide the treatment in real time (Fig. 2i).

Real-time dynamic navigation During the operation (Fig. 2g-h), the error control chart and the virtual tooth map were simultaneously displayed on the monitor, including the position, angle, and depth images of the cross-line network (Fig. 2j). The operator drilled at the indicated drilling sites from the specified angles to a depth of 1–2 mm (Fig. 2k). The position and angle windows, which were "microgreen", indicated that the actual drilling path was within the acceptable range. The depth window was "green", indicating that the puncture hole was within the predetermined depth range. When the drill was about to reach the premeasured depth, the depth window was yellow, after which the navigation operation was terminated (Fig. 2l).

The subsequent root canal retreatment was performed as previously described.

The root canal of tooth #9 was dredged with an 8# pulp canal reamer, and the lower part to the root tip of the canal was explored. The original filling material was removed, and the shape of the pulp hole of tooth #8 was corrected. The working length of tooth #9 was 19 mm, and that of tooth #8 was 20.5 mm. Postoperative periapical radiographs revealed that the root canals were properly filled (Fig. 3a-b). Three months later, teeth #8 and #9 presented no clinical symptoms. Re-examination of the periapical radiograph revealed that the apical shadow had healed (Fig. 3c). Fiber post-cores and all-ceramic restorations were performed: bonding one post, stacking the resin core, shaping, tooth preparation (Fig. 3d-e) and colour matching (Fig. 3f). Two weeks later, the zirconia all-ceramic crown was fitted with a good margin, retention and shape. The occlusal and contact points were adjusted, polished, and permanently cemented with resin adhesive. The patient was satisfied with the colour and appearance. (Fig. 3g-i). At the 6-month and 12-month follow-ups, no obvious abnormalities were found in the intraoral images (Fig. 4). This case will continue to be subject to long-term review to assess the success rate of treatment and repair and to examine any evidence of inflammatory signs and/or symptoms.

Discussion and conclusions

Different studies have shown that the long-term survival of root canal-treated teeth is often associated with major restorations [26, 27]. root canal treatment is not necessary in most PCO cases because they are asymptomatic. PCO is often noticed incidentally by discolouration of the tooth crown or a radiographic examination. Only when clinical symptoms or radiographic periapical lesions occur root canal retreatment is suggested [9]. In addition, when teeth with calcified root canals need to be

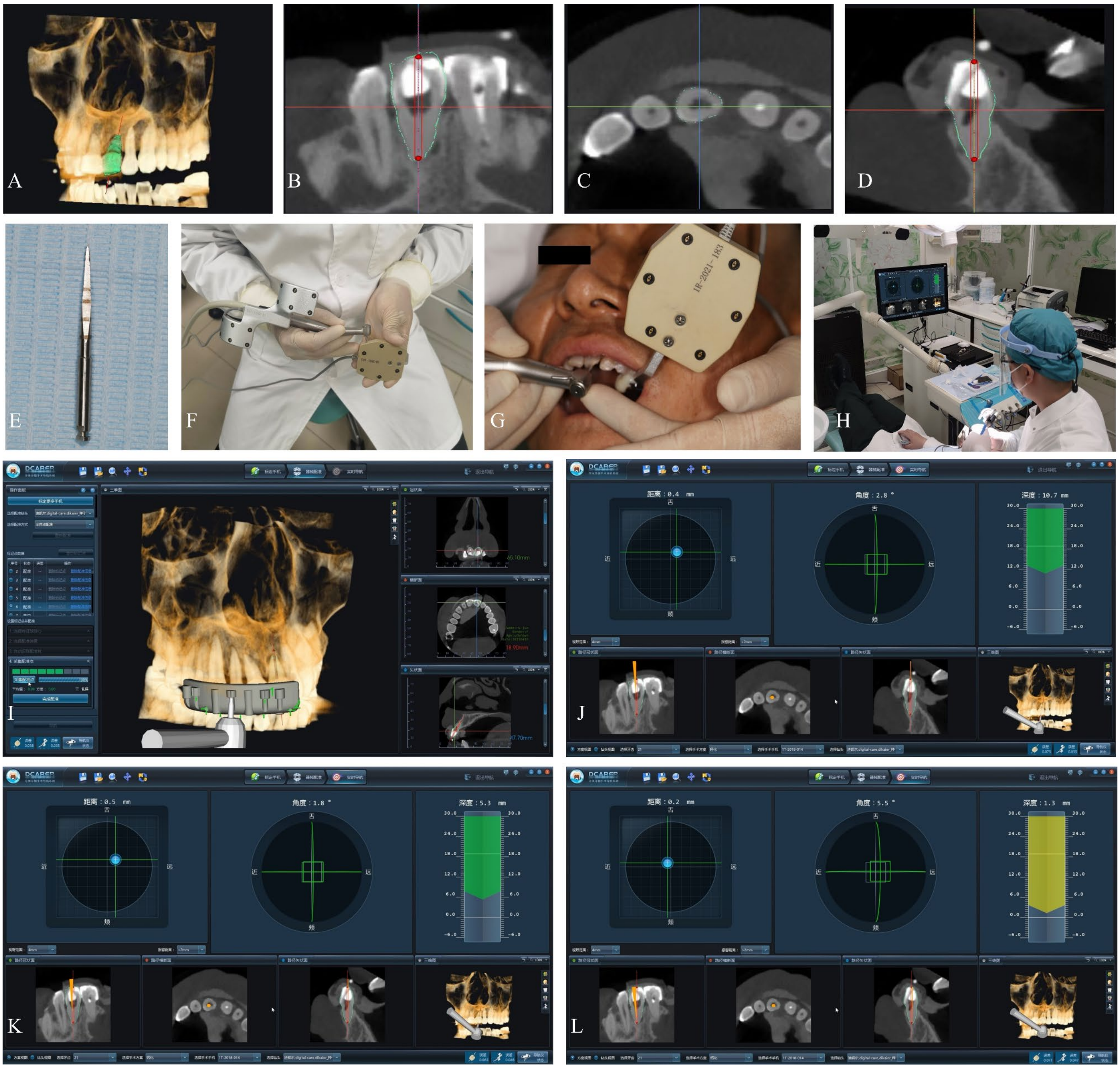

Fig. 2 The procedures of the dynamic navigation technique. **A** Locate and identify the target tooth; **B-D** Coronal, cross-sectional and sagittal views of the designed navigated access; **E** Spiculate drill used; **F** Calibration with a round bur; **G-H** Real-time dynamic navigation; **I** U-shaped registration device tube was reset to the operative dentition, and a round bur was used to select 6 registration pits and complete the registration process; **J** DNS displayed the windows when the spiculate drill reached the entry point, real-time presentation of the linear, angular and depth deviations; **K** DNS displayed the windows when the spiculate drill reached the end point; **L** DNS displayed the windows when the spiculate drill reached the end point

repaired, such as those with large defects, poor retention, and those requiring a change in the crown shape or angle, preserving a sufficient amount of residual tooth tissue, especially cervical tissue, can effectively reduce pulp-treated tooth breakage; therefore, the accuracy of hole preparation is particularly important [28].

Digital-guided endodontic treatment is more accurate for access cavity preparation, locating calcified root canals, fiber post removal, osteotomy and root-end resection [29]. Several in vitro studies have suggested that the use of dynamic or static navigation systems in endodontic treatment could achieve smaller deviations and higher success rates than freehand manipulations, and no statistically significant differences were found between the two computer-aided navigation techniques. These results suggest that guided endodontics could assist less experienced operators in obtaining highly accurate and precise results [25, 30–32]. DNS has shown satisfactory results in studies of the accuracy of calcified root canal localization in vitro. Jain et al. [33] used the Navident DNS to localize

Fig. 3 Completion of root canal retreatment and aesthetic restoration. **A-B** Steps in the root canal retreatment of tooth #9; **C** Three-month review of radiographic images, in which the root canal retreatment of tooth #8 has also been completed; **D-E** Steps of fiber post-core bonding and zirconia all-ceramic crown tooth preparation; **F** Colour matching; **G-I** Two-week review in which the all-ceramic crowns of teeth #8 and #9 were fit

Fig. 4 Clinical examinations and radiographic imaging of the patient. **A-E** 12-month review of the clinical examinations; **F-G** 6-month and 12-month review of the radiographic imaging

and guide the dredging of 138 calcified root canals in 84 3D-printed dental models by comparing the deviation between the planned path of preoperative CBCT and the actual path of postoperative CBCT; the results revealed that the mean operative time was 57.8 s, the mean deviation of the end point was 1.3 mm, and the angle deviation was 1.7°.

Dianat et al. [8] compared the accuracy and efficiency of pulpotomy between X-Guide dynamic navigation and free-hand methods in 60 occluded single root teeth from human cadavers and reported a mean distance deviation between the dynamic navigation group and the free-hand group (buccal−lingual orientation 0.19±0.21 mm vs. 0.81±0.74 mm; mesio-distally 0.12±0.14 mm vs. 0.31±0.35 mm), angular deviation (2.39° ± 0.85° vs. 7.25° ± 4.2°), dentin thickness (1.06±0.18 mm vs. 1.55±0.55 mm), and operating time (227±97 s vs. 405±246 s) ($p<0.05$). However, there was no significant difference in the success rate (96.7% vs. 83.3%) ($p>0.05$). Torres et al. [19] applied Navident dynamic navigation to 3D-printed models to evaluate the accuracy and effectiveness of its treatment for severe root canal occlusion, with 3 different experienced operators trained on 28 root canal models under dynamic navigation. Among 168 canals in 132 dental models, 156 canals were successfully established (success rate: 93%), and there was no significant difference between different operators ($p<0.05$). In addition, compared with the planned approach, the anterior apical deviation was 0.63±0.35 mm, which was significantly lower than the molar apical deviation ($p<0.05$), and the mean angular deviation was 2.81±1.53°. These findings suggest that dynamic navigation is an accurate technique for root canal treatment and has a learning curve effect. In our practice, hand‒eye coordination and control of hand movement stability using DNS require continuous training to ensure both high accuracy and efficiency, so extensive training should be performed before clinical manipulation.

Some case reports also illustrate the precise advantages of dynamic navigation in the treatment of calcified root canals. Dianat et al. [21] applied X-Guide DNS to localize and establish an approach to the calcified root canal in the distal cheek of the right upper first molar in a 63-year-old male patient. After undergoing treatment for prostate cancer with tonsillar metastasis, radiotherapy of the head and neck and treatment with psychotropic drugs, the patient chose a dynamic navigation nonsurgical approach. Villa-Machado et al. [11] reported two cases of endodontically treated upper and lower anterior teeth with discolouration of the crown and extensive occlusion of the root canals due to trauma. The patients had no subjective symptoms, the appearance of the local gingival mucosa was normal, the colour of the crown had no obvious changes, and the periapical structure was intact after 12 months. Wu et al. [13] reported the application of the DHC-ENDO1 DNS in cases of anterior root canal atresia with chronic pulpitis and periapical periodontitis, in which the DHC-ENDO1 DNS was used to successfully locate and unblock the atresia root canal and complete the root canal treatment, resulting in good postoperative recovery.

Compared with the static navigation system and free-hand method, DNS has the following advantages in the treatment of endodontic diseases: (1) significantly higher operative accuracy than the free-hand method [32]; (2) real-time adjustment of the position, angle and depth of drilling during the operation [25]; (3) better adaptability for patients with limited mouth opening, short distances between long jaw teeth, jaw tightness, and severe gag reflex [34]; (4) for patients with severe pain or difficulty in subsequent consultations, DNS can save the steps and costs of making a guide plate, so that these patients can be treated faster on the day [18]; (5) low risk of ineffective cooling of high temperatures generated during drilling [33, 35]; and (6) better manipulation to prevent tooth canal root overlapping [25]. Thus, DNS is more applicable to teeth with multiple canals. On the basis of the above advantages, DNS is optimal for creating a precise and straight path in endodontic treatment and ensuring minimally invasive pulp opening, accurate identification of calcified root canals, atraumatic fibre post removal and precise apical microsurgery [20].

At present, there are still some limitations in the clinical application of DNS of various brands compared with static navigation systems and free-hand operations: (1) the purchase cost of DNS is generally high [21]; (2) the position, angle and depth of the drill needle should be closely observed on the display screen. Therefore, good hand‒eye coordination and a certain amount of pre-training exercise are needed to increase the accuracy and success rate [36, 37]. (3) DNS devices are generally large and have limited portability [11, 35]. (4) the patient still needs to wear a retainer on the dentition that tends to extend out of the mouth through a different shape bracket; therefore, a locator plate identified by a tracer may increase patient discomfort [11, 18]. (5) needle registration must be performed in the patient's mouth, which can prolong the preoperative preparation time [20]. (6) DNS is mainly based on the CBCT data of the patients. The artefacts produced by high-impedance restorations in patients' mouths seriously affect the accuracy of locating and selecting reference points, and prepositioning marker plates on the fixator in the patient's mouth followed by a CBCT scan [38] is needed, which increases patient discomfort and the number and cost of examinations [8]. For now, the application of mixed reality (MR) or augmented reality (AR) techniques and the integration of robotics with DNS in implant placement have been reported [39, 40]. However, only in vitro studies of minimally invasive pulp opening and apical resection based on AR or robotics with DNS in endodontics have been reported [41–43]. In addition, superimposing a standard tessellation language (STL) file obtained with an intraoral scan on a CBCT image may increase the accuracy of DNS, especially when radiographic artefacts are present, but more high-quality, large sample size studies are needed to confirm these findings [44].

This case indicates that DNS could be a promising technique to save the teeth when the traditional treatment of calcified root canal approaches failure (lateral perforation), and reduce the risk of iatrogenic errors at the same time. However, there is still a lack of large sample reports on the application of DNS in guiding endodontic therapy, and further prospective clinical studies with larger sample sizes, higher quality and better designs are needed to confirm its accuracy and effectiveness.

Abbreviations

PCO	Pulp canal occlusion
DOM	Dental operating microscope
DNS	Dynamic navigation system
CBCT	Cone-beam computed tomography
DICOM	Digital imaging and communications in medicine
MR	Mixed reality
AR	Augmented reality
STL	Standard tessellation language

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Author contributions
P.X. and Q.L. helped collect the clinical data and draft and write the manuscript. Y.H. and M.X. helped with clinical data collection and analysis and revised the manuscript. L.Q. and J.W. helped with photography. F.C. designed and implemented the treatment plan and completed the follow-up examinations. H.H. supervised the study and revised the manuscript before submission. All the authors read and approved the final manuscript for publication.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Ethical approval for this study was obtained from the Ethics Committee of the First Medical Center of PLA General Hospital (No. S2023-138-01). Informed consent was obtained from the patient in written form.

Consent for publication
The patient in this report signed a written informed consent for the publication of clinical details.

Competing interests
The authors declare no competing interests.

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