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Case Report

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Guided endodontics, precision and predictability: a case series of mineralized anterior teeth with follow-up cone-beam computed tomography

Rafael Fernández-Grisales[1], Wilder Javier Rojas-Gutierrez[1], Pamela Mejía[1], Carolina Berruecos-Orozco[1], Néstor Ríos-Osorio[2,*]

[1]Endodontic Posgraduate Program, School of Dentistry, CES University, Medellín, Colombia
[2]Research Department COC-CICO, Institución Universitaria Colegios de Colombia (UNICOC), Bogotá, Colombia

ABSTRACT

Pulp chamber and root canal obliteration (PCO/RCO) presents a challenge for clinicians when nonsurgical endodontic treatment is indicated. Guided endodontics (GE) aims to precisely locate the root canal (RC) system while preserving as much pericervical dentin as possible. GE involves integrating cone-beam computed tomography (CBCT) of the affected tooth with a digital impression of the maxillary/mandibular arch, allowing for careful planning of the drilling path to the RC system through a three-dimensional (3D) static guide. This article reports four cases of teeth with PCO/RCO, accompanied by additional diagnoses of internal and external root resorption and horizontal tooth fracture, all successfully treated with GE. These cases highlight the clinical and radiographic success of GE treatments using CBCT, establishing this technique as a predictable approach for managing mineralized teeth.

Keywords: Access cavity preparation; Cone-beam computed tomography; Endodontics; Pulp calcification

INTRODUCTION

Pulp chamber/root canal obliteration (PCO/RCO) results from a defense response of the dental pulp to various noxious stimuli, such as dental trauma, orthodontic and periodontal treatment, dental caries, and restorative procedures among others [1,2]. Angiogenesis precedes dental pulp mineralization through tertiary dentine production [3]. As the pulp's perfusion declines as a consequence of damaging stimuli, the tissue must be provided with vital fluids to ensure that the healing processes proceed optimally. Angiogenesis provides oxygen and nutrition to the damaged tissue, allowing the tooth pulp to remain viable despite tissue mineralization [3]. PCO/RCO is usually an asymptomatic process and often an incidental finding during clinical and radiographic

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***Correspondence to**
Néstor Ríos-Osorio, DDS, MSc
Research Department COC-CICO, Institución Universitaria Colegios de Colombia (UNICOC), Km 20, Autonorte I-55, Chía, Cundinamarca, Bogotá 250008, Colombia
Email: nrios@unicoc.edu.co

examinations. Apical periodontitis (AP) associated with pulp necrosis following PCO/RCO, requiring endodontic treatment, has been reported in up to 30% of cases [4,5].

Mineralization of the pulp canal space develops in a coronoapical direction. Consequently, radiographically, the obliteration of the pulp space can be defined as partial pulp canal obliteration or total pulp canal obliteration [6]. The more advanced the PCO/RCO, the greater the difficulty locating the root canal (RC) space, especially when just a two-dimensional periapical radiography (PR) is available for diagnosis and treatment.

Conventional endodontic therapy in the presence of PCO/RCO is currently challenging, especially when gaining access to the RC space. Endodontic complications such as RC blockage, instrument separation, ledge formation, iatrogenic perforation, and untreated anatomy have been associated with PCO/RCO [1,2,4].

Recently, guided endodontics (GE) has been introduced as an alternate approach for addressing mineralized RCs [2,4,5,7]. The use of standard triangle language/stereolithography (STL) files from digital impression three-dimensional (3D) scanning, combined with Digital Imaging and Communications in Medicine (DICOM) files obtained from the cone-beam computed tomography (CBCT) scans, enables virtual planning of minimally invasive endodontic access, resulting in the fabrication of a 3D template. The 3D template then guides a drill into the mineralized RC space [2,4,5,7].

The current case series aims to document in detail the clinical management of advanced PCO/RCO cases employing GE in various scenarios such as radicular resorptions and horizontal fractures, with 6- to 18-month follow-up periods. The endodontic outcomes were documented with CBCT.

CASE REPORT

Case presentation

A total of four PCO/RCO clinical cases constitute this case series. We followed the CARE guidelines for reporting case reports or case series. Four Colombian patients (American Society of Anesthesiologists physical status classification I), three females and one male, aged 24 to 68 years, with a diagnosis of pulp necrosis and AP were included. Informed consent was obtained from the four patients. The common steps are detailed below.

Fabrication of the 3D endodontic template

The initial radiographic diagnosis was performed using digital PR (Gendex VisualiX eHD; Gendex, Hatfield, PA, USA). The entire arch (maxilla/mandible) was scanned (Medit i700; Medit, Seoul, Korea). High-resolution CBCT scans were acquired using the Planmeca ProMax 3D Classic (Planmeca Oy, Helsinki, Finland) with the following parameters: operating voltage, 90 kV; field of view, 50 × 40 mm; and voxel size, 75 µm. The DICOM and STL files were then imported into Planmeca software (Planmeca Romexis) and aligned. A virtual model was created, and digital burs (21 or 23 mm in length and 0.75 or 0.90 mm in diameter) were superimposed, placing the bur tip apically at the most coronal location where the calcification-free canal could be identified. A virtual sleeve was designed to keep the bur in the correct direction. When the optimal bur Course was virtually checked, the 3D endodontic guide was printed in biocompatible resin (Surgical Guide Resin; Formlabs, Somerville, MA, USA). A metal sleeve (PNEUMAT, external diameter of 3.5 mm, internal diameter of 0.75 or 0.90, height of 5 mm; FFDM Tivoly, Bourges, France) was attached to the 3D template to guide Tivoly burs 0.75- or 0.90-mm predrill and 21- or 23-mm drill or a DSP drilling system (0.80 mm in diameter and 25.5 mm in length; DSP Biomedical Group, Campo Largo, Brazil) according to each case. After printing the 3D templates, the most coronal part of the metal sleeve should allow the bur tip (once inserted) to put itself down to a depth of 21 or 23 mm (depending on each case) and reach the most coronal point of the patent RC.

Clinical procedures

Endodontic treatments were performed under infiltrative local anesthesia (Newcaina, lidocaine 2% with epinephrine 1:80,000; Newstetic, Guarne, Colombia). The 3D template was placed in the mouth and checked for proper positioning. Initially, a 1-mm-deep ameloplasty was performed with the predrill under an operating microscope (OMZ 2350; Zumax Medical Co., Suzhou, China). Subsequently, the RC was accessed using the selected drill. Predrills and drills were coupled to an

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FX23 B2 handpiece (NSK/Nakanishi Inc., Tokyo, Japan), operated at 10,000 revolutions/min with constant saline irrigation.

Following rubber dam application, apical patency was confirmed with a size 0.8 K-file (Dentsply Maillefer, Ballaigues, Switzerland). Working length was established with an apex locator (Propex Pixi; Dentsply Sirona, Charlotte, NC, USA) set to 0.5 mm and radiographically confirmed. RCs were prepared using TruNatomy Rotary Files (Dentsply Maillefer) or ProTaper Ultimate rotary files (Dentsply Maillefer), according to each case, coupled to the E-connect S Endo Motor (Eighteeth; Sifary Medical Technology Co., Changzhou, China) following the manufacturer's recommendations. The irrigation protocol included copious irrigation with 5.25% sodium hypochlorite (NaOCl) (Vista Apex Dental, Racine, WI, USA). Approximately 15 mL of NaOCL was used per RC. The final irrigation included 2 mL of 17% ethylenediaminetetraacetic acid (Vista Apex Dental) followed by a final rinse with distilled water. Irrigant solutions were administered with an IrriFlex 30-gauge irrigation needle (Produits Dentaires SA, Vevey, Switzerland), located 3 mm short of the preestablished working length. Irrigant solutions were activated using an ultrasonic tip (Irrisafe; Acteon Group, Norwich, UK). For RC obturation, a medium-sized gutta-percha master point (Dentsply Maillefer) and AH Plus Bioceramic Sealer (Dentsply Sirona) were used in a continuous wave down-pack obturation technique (System B Endodontic Heat Source; Kerr Dental, Brea, CA, USA), followed by backfill (Obtura II System; Young Specialties, Algonquin, IL, USA). Endodontic treatment was accomplished in a single visit.

Case 1: pulp chamber and root canal obliteration and apical periodontitis

A 24-year-old woman patient with a slight discoloration in tooth #11 was referred for an endodontic appointment. Clinical examination revealed pain on vertical and horizontal percussion. PR and CBCT scan showed PCO/RCO extending to the apical third of the RC (partial pulp canal obliteration), along with a periapical radiolucency/hypodense image. A diagnosis of pulp necrosis and AP was given. The patient underwent a GE procedure with a 3D endodontic guide with a metal sleeve of 3.5 mm (external diameter), 0.75 mm (internal diameter), and 5 mm (height) that guided a Tivoly drill 0.75 mm in diameter and 21 mm in length into tooth #11. Endodontic cavity access was restored with composite 1 week after GE. An 18-month follow-up with CBCT demonstrated favorable periapical healing (Figure 1).

Case 2: pulp chamber and root canal obliteration and external inflammatory resorption

A 68-year-old woman with a history of orthodontic treatment and orthognathic surgery 17 years ago, was referred by a prosthodontist for endodontic management of tooth #31. Clinical examination revealed tooth discoloration and pain upon vertical percussion. PR and CBCT scan showed partial pulp canal obliteration extending to the middle third of the RC and radiolucent/hypodense finding consistent with external inflammatory root resorption, and AP. A Vertucci type V (1-2) classification was observed in the CBCT scan; however, the GE template was designed only for the buccal canal. To get adequate access to the lingual canal, an extra extension toward the incisal side under magnification with the operational microscope and utilizing the Start-X tip #3 (Dentsply Maillefer) was required. A diagnosis of pulp necrosis and AP was given. The GE procedure was carried out with a 3D endodontic guide with a metal sleeve (3.5 mm in external diameter, 0.75 mm in internal diameter, and 5 mm in height), guiding a Tivoly drill (0.75 mm in diameter and 23 mm in length) into tooth #31. Endodontic cavity access was restored with composite one week after GE. A 6-month follow-up with CBCT is documented (Figure 2).

Case 3: pulp chamber and root canal obliteration and internal resorption

A 52-year-old woman patient with a history of orthodontic treatment 10 years ago was referred for endodontic management of tooth #13. Clinical examination revealed tooth discoloration and pain upon vertical percussion. A high-resolution CBCT scan showed partial pulp canal obliteration extending to the middle third of the RC and a hypodense finding in the apical third consistent with internal root resorption, and lateral AP. A diagnosis of pulp necrosis and AP was given. The GE procedure involved the use of a 3D endodontic guide with a metal sleeve (3.5 mm external diameter, 0.90 mm

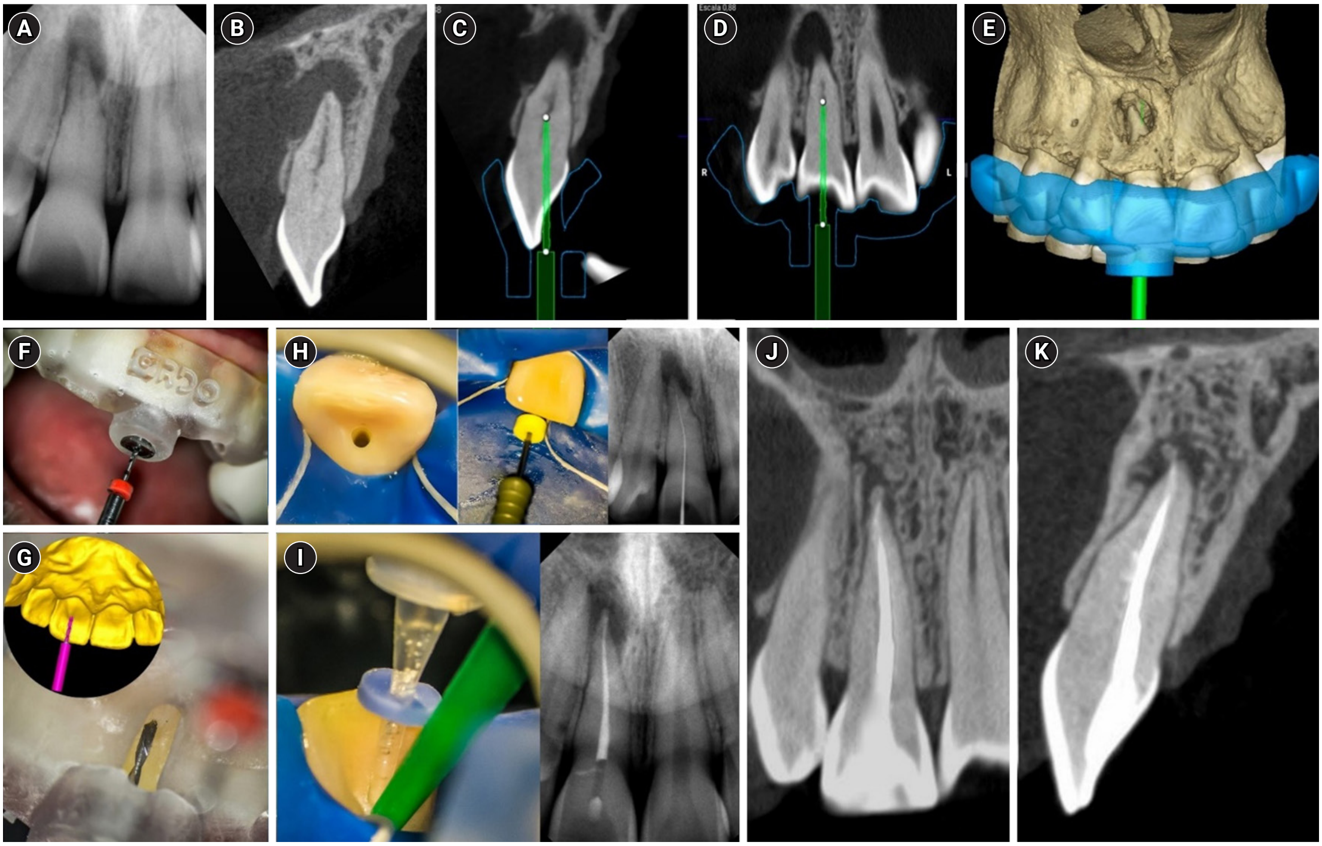

Figure 1. The sequence of planning, execution, and follow-up of guided endodontics (GE) in a maxillary central incisor. (A, B) Initial periapical radiography (PR) and cone-beam computed tomography (CBCT) of tooth #11 showing pulp chamber and root canal obliteration and apical periodontitis. (C, D) Coronal and sagittal CBCT slices illustrate the planning sequence for GE to reach the patent area of the root canal. (E) Design of three-dimensional (3D) template. (F) 3D template in the mouth. (G) Ameloplasty and verification of drill entry through the inspection windows. (H, I) Clinical sequence of GE showing a minimally invasive access cavity, verification of root canal patency, use of a 30-gauge TruNatomy irrigation needle (Dentsply Maillefer, Ballaigues, Switzerland), and final PR of the endodontic obturation. (J, K) Coronal and sagittal CBCT planes showing periapical healing 18 months after completion of the GE treatment.

internal diameter, and 5 mm height), guiding a Tivoly drill (0.90 mm in diameter and 23 mm in length) into tooth #13. Endodontic cavity access was restored with composite 1 week after that GE. The sequence of planning, execution, initial results, and 18-month follow-up were documented (Figure 3).

Case 4: pulp chamber and root canal obliteration and horizontal root fracture

A 52-year-old male patient with a history of dentoalveolar trauma 20 years ago was referred by a general dentist for endodontic treatment of tooth #11. Clinical examination revealed tooth discoloration, pain upon vertical percussion, periodontal probing depths ≤3 mm, and physiological mobility. PR and CBCT scan showed total pulp canal obliteration. The CBCT also showed a horizontal root fracture in the middle third of the root, without displacement of the coronal and apical fragments. Hypodense lesions consistent with AP and lateral periodontitis were also observed. A diagnosis of pulp necrosis and AP was given. The clinical management protocols were the same as previously described, except for the use of a DSP drilling system (0.80 mm in diameter and 25.5 mm in length) and RC preparation with the ProTaper Ultimate Shaper up to the F2 file (Dentsply Sirona). Endodontic cavity access was restored with composite 1 week after that GE. The sequence of planning, execution, and 6-month follow-up were documented (Figure 4).

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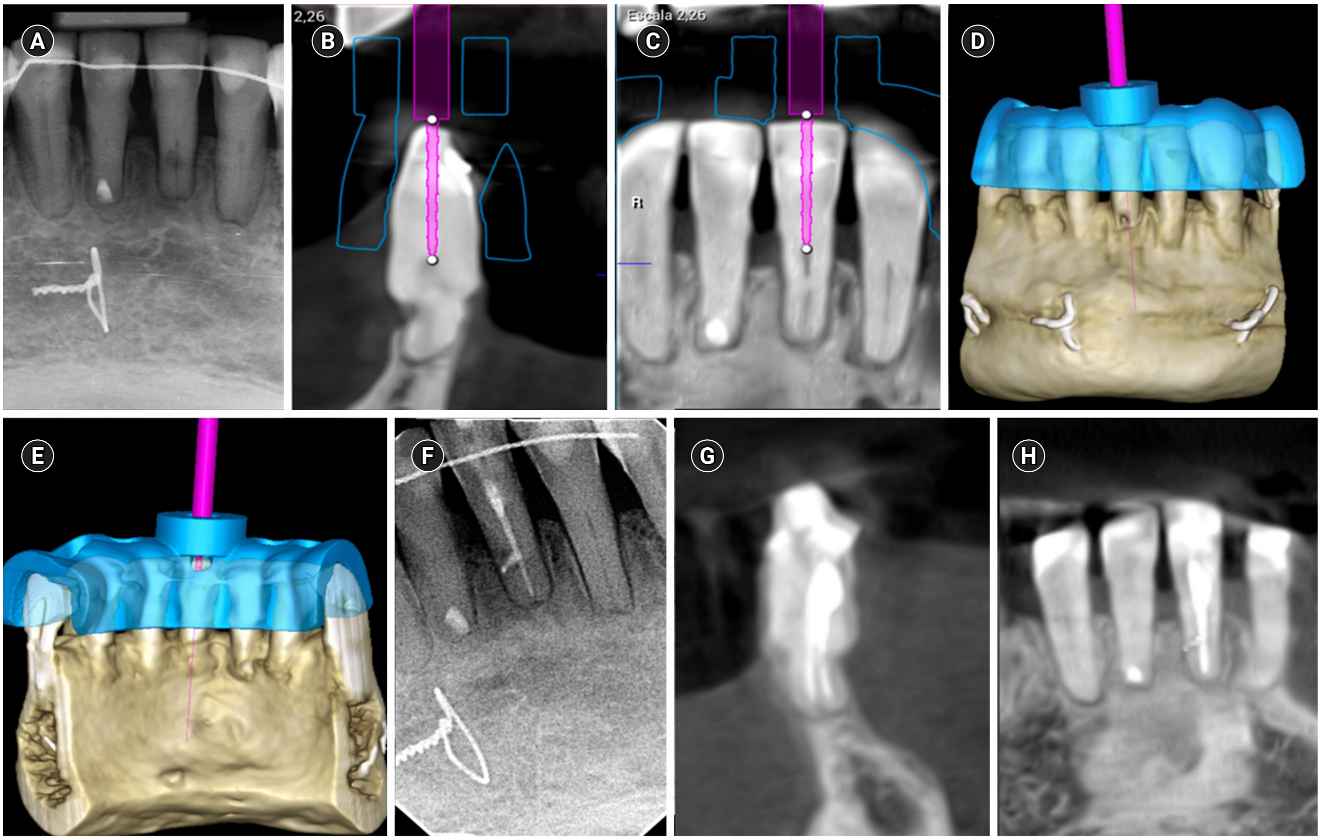

Figure 2. Guided endodontics (GE) in a mandibular central incisor with pulp chamber and root canal obliteration, external inflammatory resorption, and apical periodontitis: diagnostic, planning, and treatment sequence. (A) Diagnostic periapical radiography (PR). (B–D) Coronal, sagittal, and axial cone-beam computed tomography (CBCT) slices illustrating the planning and drilling process using the Tivoly drilling system (PNEUMAT; FFDM Tivoly, Bourges, France). (E) Integration of standard triangle language/stereolithography and DICOM (Digital Imaging and Communications in Medicine) files to create the three-dimensional template for GE. (F, G) Endodontic access. (H, I) PR showing the initial GE results and the 6-month follow-up CBCT.

DISCUSSION

PCO/RCO is caused by the increased deposition of mineralized tissue into the pulp chamber and the RC in the aftermath of external noxious stimuli. Advanced PCO/RCO presents significant challenges during nonsurgical endodontic therapy, as improper approaches may result in iatrogenic conditions and/or treatment failure [8]. GE using static navigation guides for RC localization minimizes procedural risks, optimizes clinical execution time, and ensures better treatment outcomes [9,10]. RC localization in mineralized teeth has been reported to be successful in 91.7% of patients handled by GE, compared to 41.7% in conventional freehand endodontic treatments [11,12]. These findings are consistent with the four cases of advanced PCO/RCO with AP reported in this study. In all four situations described here, the drill's anticipated position in the 3D template enabled for exact dentine removal and the canal lumen to be achieved as planned virtually. Following this phase, the canals could be rapidly and thoroughly instrumented and endodontic treatment accomplished in a single appointment. Additional findings of external resorption, internal resorption, and horizontal root fracture were observed in Cases 2, 3, and 4, respectively. Cases 2 and 4 required additional considerations in the planning and execution of GE.

In Case 2, with a Vertucci type V (1-2) [13], the GE pathway was designed only for the buccal canal; appropriate access to the lingual canal required an incisal extension of the access cavity. Surgical intervention for sealing the external resorption was not considered

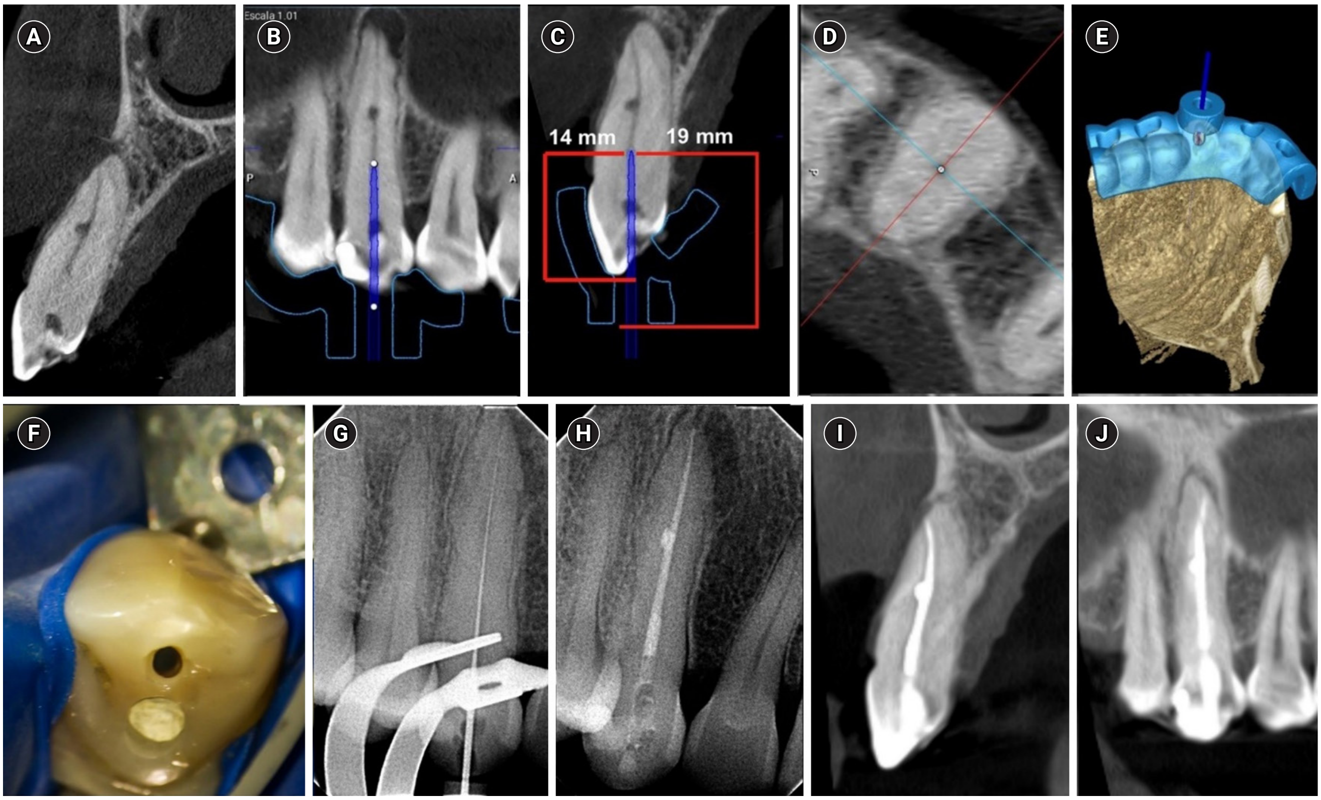

Figure 3. Guided endodontics (GE) in a maxillary canine with pulp chamber and root canal obliteration, internal resorption, and apical periodontitis: diagnostic, planning, and treatment sequence. (A) Sagittal slice of the diagnostic cone-beam computed tomography (CBCT). (B–D) Coronal, sagittal, and axial CBCT slices showing access planning and drilling using the Tivoly drilling system (PNEUMAT, FFDM Tivoly, Bourges, France). (E) Integration of standard triangle language/stereolithography and DICOM (Digital Imaging and Communications in Medicine) files to create the three-dimensional template for GE. (F, G) Endodontic access. (H–J) Periapical radiography showing the initial GE results and 18-month follow-up CBCT demonstrating periapical healing.

due to the reduced buccal cortical bone observed in the CBCT analysis, which could have compromised periodontal stability. Case 4 displayed a total pulp canal obliteration, which required the static navigation pathway to cross the horizontal root fracture line to ensure disinfection and healing of endodontic lateral and apical lesions. Endodontic treatment of the apical fragment in horizontal root fracture scenarios is unusual, due to the low incidence of pulpal involvement and restricted control during shaping and obturation through the fracture line [14]. However, the apical fragment, in this case, revealed AP. Notably, the horizontal root fracture line was incomplete towards the buccal aspect, allowing drilling through both fragments. In this scenario, evaluating the possibility of irrigating agent extrusion due to the horizontal root fracture is critical. Although the CBCT findings indicated that both apical and coronal fragments had not been displaced, increased irrigation force or pressure should be avoided to prevent NaOCl extrusion. Surgical removal of the apical fragment following a horizontal root fracture has also been reported as a treatment option [14]. Nevertheless, we did not consider a surgical approach due to the biological cost, considering the integrity of the buccal and palatal cortical bones. The 6-month follow-up CBCT obtained for this case shows a successful periapical healing.

All of the clinical cases presented here involved minimally invasive endodontic access and RC instrumentation with low-taper shaping systems aiming at protecting the integrity of the pericervical dentin, which is deemed critical for the biomechanical behavior of endodontically treated teeth [1,15]. The obturation ap-

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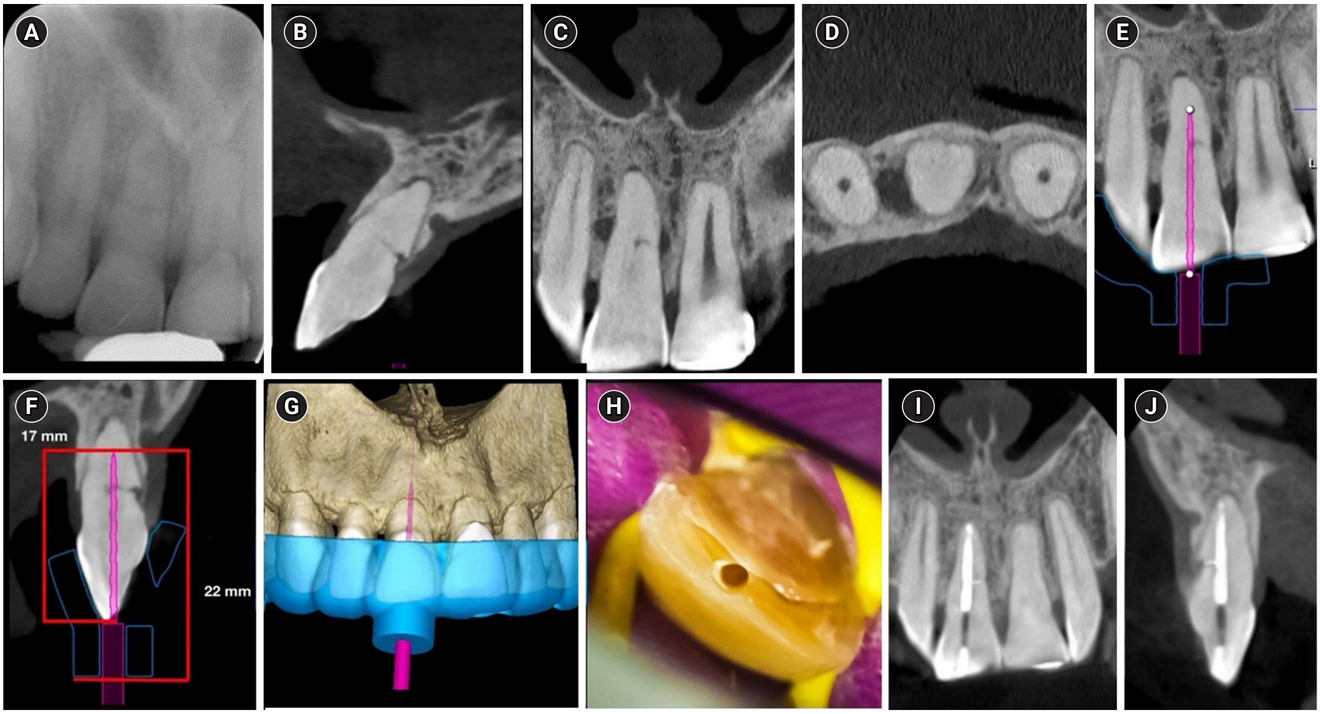

Figure 4. Guided endodontics (GE) in a maxillary central incisor with complete pulp chamber and root canal obliteration, horizontal root fracture, and apical and lateral periodontitis: diagnostic and treatment sequence. (A) Diagnostic periapical radiography. (B–D) Coronal, sagittal, and axial slices of the diagnostic cone-beam computed tomography (CBCT). (E, F) Access planning and drilling with the DSP system (DSP Biomedical Group, Campo Largo, Brazil). (G) Integration of standard triangle language/stereolithography and DICOM (Digital Imaging and Communications in Medicine) files to create the three-dimensinal template for GE. (H) Minimally invasive endodontic access for GE. (I, J) Six-month follow-up CBCT demonstrating periapical healing.

proach for this case series featured AH Plus Bioceramic (Dentsply Sirona) as a sealing cement in conjunction with a continuous wave down-pack obturation technique followed by backfill. AH Plus Bioceramic is a hydraulic calcium silicate-based sealer that exhibits high alkalinity, calcium ion release, apatite formation, and mineralization. Warm obturation is more effective than lateral compaction in filling complex RCs because it increases gutta-percha density and creates occlusions ideal for irregular RCs. However, it has been claimed that high heat can affect the physiochemical qualities of calcium silicate-based sealers [16]. A recent study using Fourier-transform infrared spectroscopy proved that the chemical composition of AH Plus Bioceramic didn't alter at elevated temperatures, leading to the conclusion that AH Plus Bioceramic possesses favorable physicochemical properties, making it suitable for thermal applications [16].

In all of the cases described here, closed static endodontic guides were employed. An alternative approach known as the 2ingis (Brussels, Belgium) has also been proposed. The 2ingis system employs an open static endodontic guide that directs not the drill but the head of the contra-angle. The 2ingis technique provides irrigation during drilling and allows the use of any form of bur, including small-diameter, long-necked round burs, and diamond burs, which can create direct access into the enamel [17]. The closed static guide approach has the drawback of preventing abundant irrigation during the drilling phase, which increases the possibility of collected dentin debris and, most likely, metal debris caused by drilling through the sleeve. Poor irrigation will also cause the drill and tooth to overheat. As a result, it is critical to progress carefully with the drill, pausing and rinsing in between each stage.

Dynamic navigation is another alternative method for performing GE. The dynamic navigation system is a computer-aided guided technology initially designed

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for precise implant placement. The computer delivers real-time feedback while the drill path is created. The technology connects many cameras and motion-tracking devices to the dental handpiece and patient. It continuously compares the created path with the planned drill path using software on CBCT pictures of teeth [18]. Several research have confirmed the validity of both static and dynamic techniques [11]. Although it has been reported that the employment of static guidance results in a much larger mean angular deviation (10.04°) compared to dynamic navigation (5.58°) [19], a recent systematic review and meta-analysis found no statistically significant differences between the two approaches in terms of RC location rate, with static and dynamic techniques demonstrating success rates of 98.5% and 94.5%, respectively [11,20].

Finally, it is crucial to note that the usage of GE with static navigation guides may present various limitations. It is important to keep in mind that the surgical template's design and manufacturing process play a significant role in the technique's precision [11]. To provide stability, numerous teeth must be isolated throughout the process so that the guide can fit directly on them. Therefore, to check the path during endodontic treatment, the guide must be removed since it inhibits visual access to the cavity. Static guiding, particularly in posterior teeth, necessitates the production of many templates to provide direct access to individual RCs. Clinical limitations include the need for a straight path to the target, making static-guided approaches challenging to use in small mouth openings or posterior teeth with little interocclusal space. In clinical scenarios involving mineralized canals after a root curve, endodontic surgery is the most appropriate treatment approach. Larger diameter slow-speed drills can cause fissures on the tooth surface and generate excessive heat, potentially harming the periodontal ligament. Additionally, the lack of 3D real-time imaging hinders intraoperative adjustments to the established drill trajectory [11,21–24].

GE proved to be a precise and predictable technique for treating teeth with advanced PCO/RCO, which may also present with internal root resorption, external root resorption, and horizontal root fracture, accompanied by AP. All reported clinical cases were successfully treated with no complications during the procedure. The technique was executed based on 3D planning.

CONCLUSIONS

GE provided a highly precise and predictable treatment alternative for advanced PCO/RCO cases. Each case was managed using a minimally invasive approach, with successful outcomes documented through CBCT.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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None.

AUTHOR CONTRIBUTIONS

Conceptualization, Funding acquisition, Project administration, Resources: Fernández-Grisales R. Formal analysis: Berruecos-Orozco C. Investigation: Berruecos-Orozco C, Rojas-Gutierrez WJ. Methodology: Mejía P, Rojas-Gutierrez WJ. Software: Mejía P. Supervision: Fernández-Grisales R, Rojas-Gutierrez WJ. Validation: Mejía P, Berruecos-Orozco C, Rojas-Gutierrez WJ. Visualization: Ríos-Osorio N. Writing - original draft: Fernández-Grisales R, Ríos-Osorio N. Writing - review & editing: Ríos-Osorio N.

DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

REFERENCES

1. Chaniotis A, Ordinola-Zapata R. Present status and future directions: management of curved and calcified root canals. Int Endod J 2022;55 Suppl 3:656-684.
2. Abbott PV, Yu C. A clinical classification of the status of the pulp and the root canal system. Aust Dent J 2007;52(1 Suppl):S17-S31.
3. Caviedes-Bucheli J, Gomez-Sosa JF, Azuero-Holguin MM, Ormeño-Gomez M, Pinto-Pascual V, Munoz HR. Angiogenic mechanisms of human dental pulp and their relationship with substance P expression in response to occlusal trauma. Int Endod J 2017;50:339-351.
4. Connert T, Weiger R, Krastl G. Present status and future directions: guided endodontics. Int Endod J 2022;55 Suppl 4:995-1002.

https://doi.org/10.5395/rde.2025.50.e4

5. Moura LB, Velasques BD, Silveira LF, Martos J, Xavier CB. Therapeutic approach to pulp canal calcification as sequelae of dental avulsion. Eur Endod J 2017;2:1-5.
6. Vinagre A, Castanheira C, Messias A, Palma PJ, Ramos JC. Management of pulp canal obliteration-systematic review of case reports. Medicina (Kaunas) 2021;57:1237.
7. Nasiri K, Wrbas KT. Management of calcified root canal during root canal therapy. J Dent Sci 2023;18:1931-1932.
8. Lewis NV, Aggarwal S. Static guided endodontic approach for pulp canal obliteration: a case report. Cureus 2023;15:e42379.
9. Panithini DB, Sajjan GS, Kinariwala N, Medicharla UD, Varma KM, Kallepalli M. Real-time guided endodontics: a case report of maxillary central incisor with calcific metamorphosis. J Conserv Dent 2023;26:113-117.
10. Zehnder MS, Connert T, Weiger R, Krastl G, Kühl S. Guided endodontics: accuracy of a novel method for guided access cavity preparation and root canal location. Int Endod J 2016;49:966-972.
11. Ribeiro D, Reis E, Marques JA, Falacho RI, Palma PJ. Guided endodontics: static vs. dynamic computer-aided techniques: a literature review. J Pers Med 2022;12:1516.
12. Connert T, Krug R, Eggmann F, Emsermann I, ElAyouti A, Weiger R, *et al*. Guided endodontics versus conventional access cavity preparation: a comparative study on substance loss using 3-dimensional-printed teeth. J Endod 2019;45:327-331.
13. Karobari MI, Parveen A, Mirza MB, Makandar SD, Nik Abdul Ghani NR, Noorani TY, *et al*. Root and root canal morphology classification systems. Int J Dent 2021;2021:6682189.
14. Sheikhnezami M, Shahmohammadi R, Jafarzadeh H, Azarpazhooh A. Long-term outcome of horizontal root fractures in permanent teeth: a retrospective cohort study. J Endod 2024;50:579-589.
15. Chan MY, Cheung V, Lee AH, Zhang C. A literature review of minimally invasive endodontic access cavities: past, present and future. Eur Endod J 2022;7:1-10.
16. Kim HI, Jang YE, Kim Y, Kim BS. Physicochemical changes in root-canal sealers under thermal challenge: a comparative analysis of calcium silicate- and epoxy-resin-based sealers. Materials (Basel) 2024;17:1932.
17. Bordone A, Cauvrechel C. Treatment of obliterated root canals using various guided endodontic techniques: a case series. G Ital Endod 2020;34:23-34.
18. Vasudevan A, Santosh SS, Selvakumar RJ, Sampath DT, Natanasabapathy V. Dynamic navigation in guided endodontics: a systematic review. Eur Endod J 2022;7:81-91.
19. Villa-Machado PA, Restrepo-Restrepo FA, Sousa-Dias H, Tobón-Arroyave SI. Application of computer-assisted dynamic navigation in complex root canal treatments: report of two cases of calcified canals. Aust Endod J 2022;48:187-196.
20. Zubizarreta-Macho Á, Valle Castaño S, Montiel-Company JM, Mena-Álvarez J. Effect of computer-aided navigation techniques on the accuracy of endodontic access cavities: a systematic review and meta-analysis. Biology (Basel) 2021;10:212.
21. van der Meer WJ, Vissink A, Ng YL, Gulabivala K. 3D Computer aided treatment planning in endodontics. J Dent 2016;45:67-72.
22. Torres A, Shaheen E, Lambrechts P, Politis C, Jacobs R. Microguided Endodontics: a case report of a maxillary lateral incisor with pulp canal obliteration and apical periodontitis. Int Endod J 2019;52:540-549.
23. Torres A, Lerut K, Lambrechts P, Jacobs R. Guided endodontics: use of a sleeveless guide system on an upper premolar with pulp canal obliteration and apical periodontitis. J Endod 2021;47:133-139.
24. Buchgreitz J, Buchgreitz M, Bjørndal L. Guided endodontics modified for treating molars by using an intracoronal guide technique. J Endod 2019;45:818-823.