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Guided Endodontics- Static & Dynamic: A Review

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KEYWORDS

3D printing, CAD/CAM technology, CBCT imaging, Dynamic navigation, Guided endodontics, Static navigation

ABSTRACT:

Guided endodontics has emerged as a transformative innovation in managing complex endodontic cases, especially those involving pulp canal obliteration and atypical root canal morphology.

Static navigation involves the use of 3D-printed templates based on CBCT and surface scans, ensuring precise and minimally invasive access to root canals.

Dynamic navigation offers real-time visual guidance using stereoscopic tracking systems, allowing intraoperative flexibility. Both techniques significantly enhance accuracy, reduce iatrogenic errors, and preserve pericervical dentin, thus aligning with minimally invasive dentistry principles.

This review outlines the fundamental concepts, methodologies, and clinical uses of both static and dynamic approaches in guided endodontics. It also discusses indications, limitations, software planning, and the role of digital technologies like CAD/CAM and 3D printing in implementing guided endodontics.

Collectively, these advances offer safer, more predictable, and efficient treatment outcomes in endodontics.

Introduction

Endodontic treatment success relies heavily on the precise identification, negotiation, and debridement of the root canal system. The initial and most critical step in this process is access cavity preparation, which allows for proper canal identification and subsequent disinfection.[1] However, in teeth presenting with pulp canal obliteration (PCO), calcified canals, or complex anatomical variations such as dens invaginatus, achieving a suitable access cavity can be extremely challenging[2] Conventional techniques in such cases are often associated with procedural errors like canal deviation, root perforation, or excessive removal of dentin, compromising both tooth structure and treatment prognosis.[3,4]

The principles of minimally invasive endodontics (MIE) advocate for preserving as much sound tooth structure as possible, particularly the pericervical dentin, which plays a crucial role in the biomechanical stability of the tooth. Emerging technologies now enable clinicians to overcome traditional limitations by integrating digital imaging, computer-aided design (CAD), and additive manufacturing (3D printing) into clinical practice.

Guided endodontics, which includes **static navigation** using 3D-printed templates and **dynamic navigation** utilizing real-time motion

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tracking, represents a novel, precise, and conservative approach to managing complex endodontic cases [5]. These techniques have been successfully applied in locating calcified canals, managing anatomical anomalies, removing fiber posts, and guiding endodontic microsurgeries. [6] By merging cone-beam computed tomography (CBCT) data with surface scans, guided access allows for targeted canal entry with enhanced predictability and safety.

This review explores the current applications, advantages, limitations, and future directions of static and dynamic guided endodontics, emphasizing their role in enhancing treatment outcomes and preserving tooth integrity in complex clinical scenarios.

Need for 3D Guided Endodontics

Guided Endodontics, also known as Targeted Endodontic Treatment (TET), enhances the accuracy and predictability of complex endodontic procedures such as managing calcified canals, pulp canal obliteration, and endodontic microsurgeries. Traditional access approaches often risk iatrogenic errors, especially in teeth with complex anatomy or calcification. In contrast, guided techniques—static (SGE) or dynamic (DGE)—utilize CBCT data and optical scans to create virtual drill paths, ensuring precise, minimally invasive access.[7]

Static guidance relies on a prefabricated guide derived from merged CBCT and intraoral scans, while dynamic navigation uses real-time tracking of the drill's position relative to pre-planned CBCT-based paths. Both methods are particularly valuable for cases involving pulp canal obliteration, calcifications, abnormal morphologies (e.g., dens invaginatus), apicoectomy, osteotomy, and fiber post removal.[8].

Types of Guided Endodontics

Guided endodontics is classified into two main types: Static Guided Endodontics (SGE) and Dynamic Guided Endodontics (DGE).

- **Static Guided Endodontics (SGE)** uses preoperative CBCT and surface scans (intraoral or model-based) to design a 3D-printed guide. This guide, with a metal sleeve, directs the drill to the calcified canal with a predetermined angulation and depth. It ensures precise, minimally invasive access, especially in anterior teeth with straight canals.
- **Dynamic Guided Endodontics (DGE)** utilizes CBCT data in combination with real-time tracking through a stereo camera and reference markers. It enables the clinician to continuously view and modify the drill trajectory in real time throughout the procedure. DGE offers flexibility and is particularly useful in cases where a static guide is impractical, such as in patients with limited mouth opening or complex anatomy.[9]

CBCT in Guided Endodontics

Cone-Beam Computed Tomography (CBCT) plays a pivotal role in 3D Guided Endodontics, offering detailed visualization of root canal anatomy, especially in cases with pulp canal obliteration (PCO) or complex morphology. [10]

Compared to conventional radiographs, CBCT provides superior spatial resolution, particularly in axial, sagittal, and coronal planes, aiding in accurate treatment planning.

Despite its diagnostic value, CBCT involves higher radiation doses, although modern limited field-of-view devices have reduced exposure (~5 µSv). Adherence to the ALARA principle is essential, especially in younger patients.[11]

The European Society of Endodontology recommends CBCT use in cases of severe calcifications or apical periodontitis, where it supports the planning and execution of guided access with higher predictability.

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Digital Impression Systems, CAD/CAM, and STL File Formats

Computer-Aided Design and Manufacturing (CAD/CAM) systems in dentistry integrate hardware and software to perform three key functions:

1. 3D data acquisition from dental structures,
2. Digital restoration design, and
3. Automated fabrication of dental restorations.

Digital impressions are acquired using:

- **Direct scanning** with intraoral scanners, capturing structures such as teeth or implants directly from the patient's oral cavity.
- **Indirect scanning** via extraoral desktop or laboratory scanners, which digitize physical models or impressions outside the mouth.

Evolution of Dental CAD/CAM

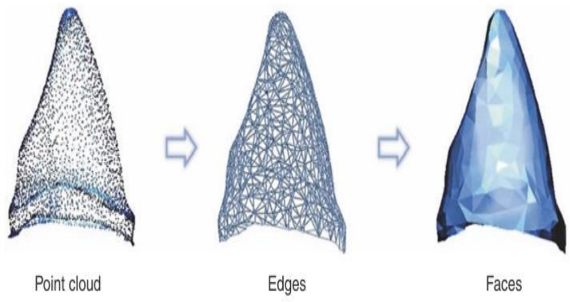
- Dr. François Duret pioneered dental CAD/CAM systems, patenting the first complete system, *Sopha System*, in 1984. His work laid the foundation for modern digital dentistry.

STL File Format and 3D Data Structure

The STL (Standard Tessellation Language) file format is the most widely used format for storing 3D dental data. It depicts the surface structure through a mesh composed of interconnected triangular elements. STL data is typically generated from intraoral scans and is essential for CAD modeling and 3D printing.

The STL mesh is composed of:

- Vertices (point cloud),
- Edges (connecting lines between points),
- Faces (triangular surfaces defined by three edges).



DICOM

DICOM (Digital Imaging and Communications in Medicine) is the international standard for handling, storing, and transmitting medical imaging information, including **Cone-Beam Computed Tomography (CBCT)** data. In guided endodontics, it is critical for planning minimally invasive procedures with high accuracy.

Role of DICOM in Guided Endodontics[12]:

Step	Function of DICOM
1. CBCT Acquisition	CBCT scans of the patient's teeth, jaw, and root structure are exported in DICOM format.
2. Data Import	DICOM files are imported into planning software (like Blue Sky Plan, 3Shape, or coDiagnostiX).
3. Image Merging	DICOM is often merged with STL files from intraoral scans to create a precise 3D model.
4. Treatment Planning	The clinician plans the access cavity or surgical path virtually, based on the anatomical detail from the DICOM.
5. Guide Design	The drill path is aligned digitally, and a surgical guide is created using 3D printing.

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Advantages of Using DICOM in Guided Endodontics

Feature	Benefit
High-resolution anatomical detail	Enables precise visualization of calcifications, canal path, and periapical structures.
Volumetric data	Essential for planning angulation and depth of access.
Interoperability	Compatible with most dental planning and 3D printing software.
Non-destructive, reproducible	Planning can be verified or revised without retaking scans.

Endodontic Guides

A 3D endodontic guide (or endoguide) is a custom-fabricated template used in static guided endodontics to direct drills along a pre-planned path for accessing calcified canals or performing root-end surgeries. It ensures accuracy, minimizes tissue removal, and improves clinical outcomes.

Types of Endodontic Guides:

- **By Use**:
  - *Non-surgical guides*: For locating calcified canals.
  - *Surgical guides*: For procedures like root-end resection.
- **By Support**:
  - *Tooth-supported*: Most common; rests on existing dentition.
  - *Mucosa-supported* and *bone-supported*: Used in specific surgical cases.
- **By Design Purpose**:
  - From soft tissue retractors to full guides for bone trephination.
  -

Guide (Template) Material

Material Type	**Common Name**	**Properties**	**Applications**
Biocompatible Photopolymer Resin	Surgical Guide Resin (e.g., Formlabs Surgical Guide Resin, NextDent SG, 3D Systems VisiJet M2S-HT90)	- Biocompatible - Sterilizable- Dimensional stability- High accuracy (±100 µm)	Used to 3D-print endodontic guides that direct the bur or drill into the planned path
Poly(methyl methacrylate) (PMMA)	Dental acrylic	- Good strength- Easily millable- Economical	Used in CAD-CAM milled guides (less common than 3D printed)
Thermoplastic materials (e.g., PLA, ABS)	Hobby-level materials	- Low-cost- Used mainly in research or training	Not suitable for clinical use due to lack of biocompatibility and sterilizability

Steps in Guide Planning

1. CBCT and surface scanning: Capture 3D anatomy (DICOM and STL files).

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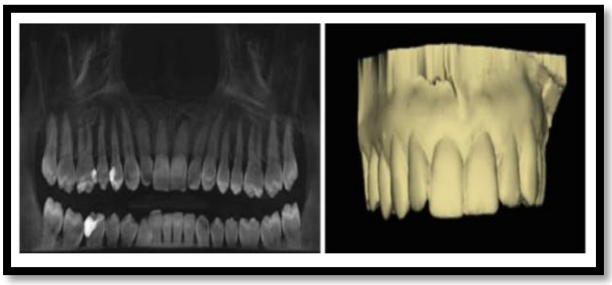
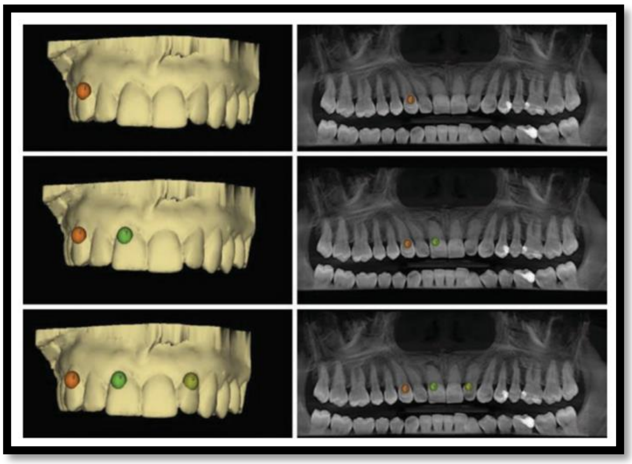


CBCT (DICOM data) and Surface scan (STL file) of the patient [23]

2. Data merging: Superimpose scans using software for accurate virtual planning.

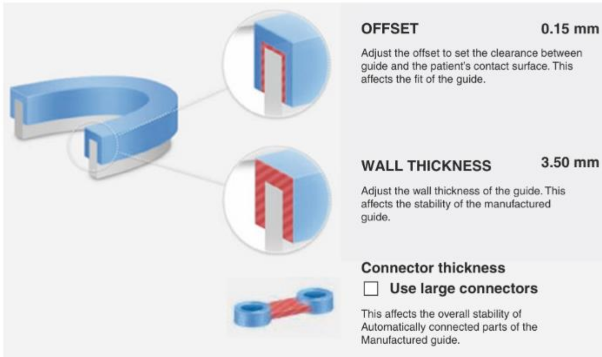


Superimposition of CBCT data and surface scan by marking three spots on both of them[23]

3. Designing the guide:

- Canal tracing and virtual drill path creation with defined target, angle, and drill diameter.
- Sleeve selection: Guide sleeves preferred for stability and accuracy.
- Considerations include guide offset, wall thickness, inspection windows, and adjacent tooth coverage.

Once finalized, the guide design is exported as an STL file for 3D printing, offering a precise and minimally invasive solution for challenging endodontic treatments.[13]



Software Systems for Endoguide Planning

Guided endodontics relies on specialized software to plan virtual drill paths and fabricate accurate endodontic guides. Initially adapted from implantology, software like **Implant Studio**, **Implant Station**, and **coDiagnostiX®** has been repurposed for endodontic applications. **SICAT Endo** is one of the few programs developed specifically for endodontics.

Popular software used in guide planning includes:

- **coDiagnostiX®**: Allows detailed planning using CBCT and STL data, including segmentation, virtual drill path planning, and guide customization with options for sleeve design and documentation.
- **2Ingis®**: A sleeveless guide system using SMOP software for linear drill guidance, designed and fabricated externally. It allows better irrigation and reduced heat generation during procedures.
- **DDS Pro** and **Acteon® AIS**: Provide superimposition tools, drill path planning, and guide design. Though not fully customized for endodontics, they are widely used due to their compatibility and functionality.

Despite advancements, current software often lacks a comprehensive endodontic file library. Thus, guided systems primarily assist in canal localization, while effective cleaning and shaping remain critical for treatment success.[14]

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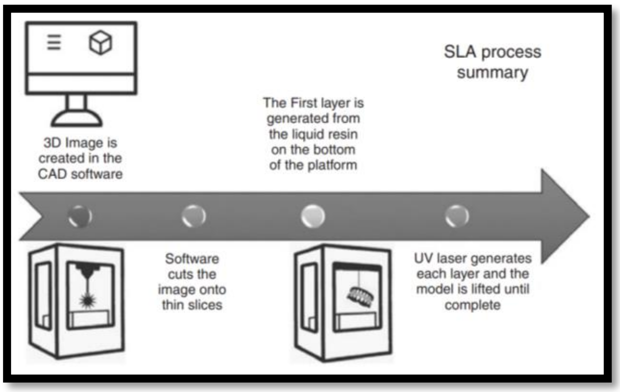
3D Printing in Endodontics

3D printing, also known as additive manufacturing, has significantly transformed endodontic diagnostics and treatment by enabling customized, accurate, and reproducible models and surgical guides. It has clinical, experimental, and educational applications in endodontics. [15]

The 3D printing workflow involves:

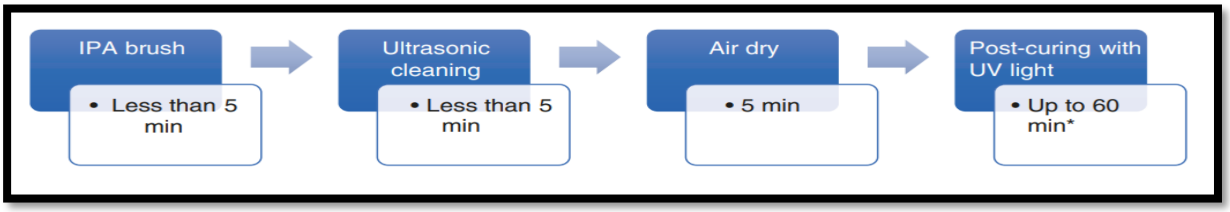
1. Image acquisition (via CBCT, intraoral, or optical scanners)
2. Digital design and STL file generation, and
3. Fabrication using 3D printers.

Common 3D printing technologies include SLA/DLP, FDM, SLS, and bioprinting. Among these, **SLA**/DLP is most widely used in dentistry because of its superior resolution and precision.



Summary of process of 3D printing with SLA printer.[23]

Postprocessing steps—cleaning, curing, and disinfection—are critical to ensure strength, accuracy, and biocompatibility of printed models or guides.



Steps of postprocessing of 3D printed guides.[23]

In endodontics, 3D printing is used to:

- Create endodontic guides for canal access or surgeries,
- Create anatomical models for detailed case planning or educational purposes
- Assist in guided endodontic procedures with increased precision and reduced chair time

By combining CBCT imaging and digital workflows, 3D printing enables minimally invasive, patient-specific solutions, enhancing outcomes in complex endodontic treatments.

Clinical Applications of Guided Endodontics:

- **Access Cavity Preparation**: Guided access improves precision and preserves tooth structure, even in ultra-conservative access designs.
- **Management of Calcified Canals**: Significantly reduces perforation risk and operator-dependent errors.
- **Apicoectomy and Osteotomy**: Enables flapless or minimally invasive approaches with accurate apex localization.
- **Fiber Post Removal**: Allows safe and efficient retrieval while minimizing dentin loss.

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Static Guided Nonsurgical Approach for Calcified Anterior Canals

Pulp canal obliteration (PCO) in anterior teeth can complicate access and canal negotiation, increasing the risk of perforation and excessive dentin loss [16]. Static guided endodontics, using CBCT and intraoral/scan data, enables precise drill path planning through a 3D-printed guide, ensuring minimally invasive access to the calcified canal.

Limitations include:

- Inapplicability in curved canals,
- Need for a stable tooth during imaging and drilling,
- Distortion due to metallic restorations,
- Limited availability of slender, long drills and sleeves.

Despite these challenges, static guided access offers a highly accurate, conservative, and predictable solution for managing calcified anterior canals.

Static Guided Non-surgical Approach for Posterior Teeth

Indications:

- **Calcified canals:** Effective for managing calcifications in molar roots
- **Minimally Invasive Endodontics (MIE):** Preserves healthy coronal, cervical, and radicular tooth structure by precisely directing access according to canal anatomy, protecting pericervical dentin.
- **Selective Root Re-treatment:** Enables targeted retreatment of roots with periapical pathology in multi-rooted teeth, preserving unaffected roots, aided by CBCT imaging for accurate diagnosis and planning. [17]

Treatment Planning Considerations:

- Adequate inter-occlusal distance is crucial for guide and drill placement; if limited, options include short burs or angulated drill paths.
- Accessibility can be evaluated using silicone mock guides to simulate drill movement before treatment.

Drills and Sleeves:

- Drill diameters range from 0.75 to 1.2 mm; specialized endodontic guide burs and sleeves are used, often 3D printed with the guide.

Procedure Highlights:

1. Verify guide stability and dimensional accuracy of drills.
2. Mark entry points, remove enamel/restoration freehand, then use the guide for dentin drilling.
3. Use short burs initially, switching to longer burs after coronal third to avoid wobbling.
4. Drill intermittently with coolant to prevent overheating.
5. Scout and negotiate canals after guided access, then complete biomechanical preparation.

Potential Mishaps:

- **Unstable guides** may cause over-preparation or perforations; ideal offset in software (~0.15 mm) and use of fixation improve stability.
- **Inaccurate drilling** can result from CBCT artifacts, unstable guides, or faulty planning; precautions include creating a small ditch in previously accessed teeth or using intra-coronal guides.

Static Guided Approach in Surgical Endodontics (SGE)

Static Guided Endodontics (SGE) has extended its applications from nonsurgical root canal

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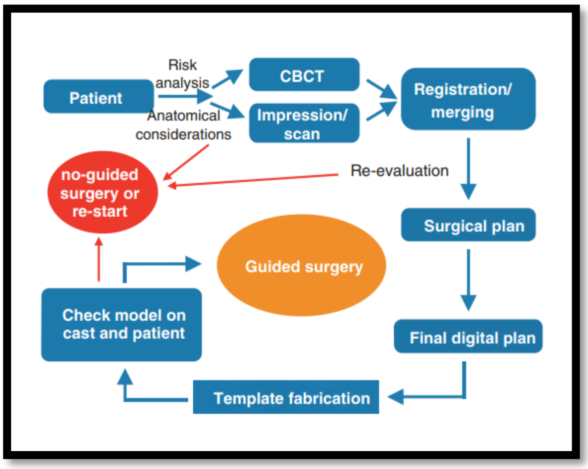
localization to surgical endodontic procedures such as osteotomy and apicoectomy. These procedures utilize 3D-printed surgical templates generated from CBCT and intraoral surface scans. The guides provide accurate, minimally invasive access to the apex of the root, enabling precise bone trephination and root-end resection, while minimizing soft tissue trauma.

This approach is particularly advantageous in:

- Anatomically complex areas (e.g., palatal roots, dense bone),
- Flapless or minimally invasive surgeries, and
- Cases requiring retreatment or resection near vital structures.

Benefits of the guided surgical technique include:

- Increased accuracy and replicability,
- Reduced operative time,
- Limited damage to adjacent tissues,
- Improved postoperative recovery. [18]



Dynamic Navigation in Endodontics

Dynamic navigation (DN) is an advanced, real-time computer-assisted technology derived from implantology that is now being applied in endodontics for both nonsurgical and surgical procedures. It allows precise drill guidance using CBCT data and optical tracking systems. The system continuously maps the handpiece and drill in relation to the patient's anatomy, enhancing accuracy and minimizing procedural errors. [19]

Principles and Workflow

DN systems comprise a stereoscopic camera, a navigation software platform, and reflective markers on the patient and handpiece. The workflow includes:

CBCT imaging and virtual drill path planning.

Registration (trace-based matching of CBCT data to patient anatomy).

Calibration of the drill tip and handpiece.

Tracking the drill in real time during the procedure.

Applications

Nonsurgical Endodontics: Especially beneficial in cases of calcified canals, DN allows minimal, accurate access cavity preparation while preserving pericervical dentin.

Surgical Endodontics: Used for apicoectomies, DN enhances apex localization and enables minimally invasive osteotomy and root-end resection.

Advantages

Real-time accuracy and feedback

Minimally invasive, flapless approaches

No need for surgical guide fabrication

Reduced operative time and improved healing

Compatibility with standard dental equipment

Limitations

High system cost and software dependency

Learning curve and need for clinical training

- Requires intraoperative space for camera tracking

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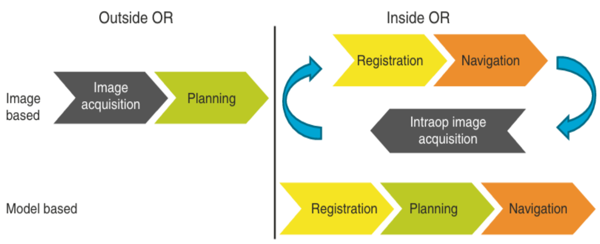

CLINICAL EXAMPLES OF GUIDED ENDODONTICS

Clinical Case 1 – Guided Access in a Calcified Central Incisor [20]

[Fonseca Tavares WL, Diniz Viana AC, de Carvalho Machado V, Feitosa Henriques LC, Ribeiro Sobrinho AP. Guided endodontic access of calcified anterior teeth. *J Endod*. 2018 Jul;44(7):1195–9.]

A 43-year-old female with a history of trauma presented with a calcified maxillary central incisor and apical periodontitis. CBCT showed canal visibility only in the apical third. Guided endodontics was chosen.

CBCT and model scans were merged, and a virtual drill path was planned. A 3D-printed guide directed a low-speed bur to the canal. The canal was located, instrumented, and obturated. The tooth was asymptomatic at 15-day follow-up.

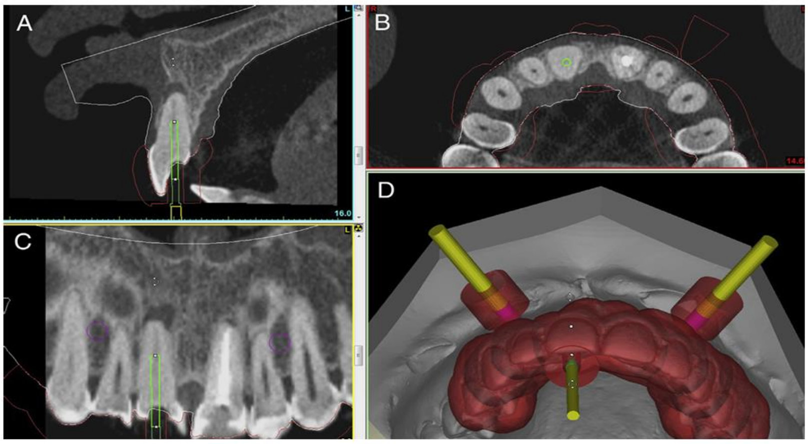

Figure 1. A CBCT image of the right maxillary central incisor with severe PCC and apical periodontitis. (*A–C*) Virtual planning of guided endodontics. (*D*) The model scan aligned to the 3D template and the virtual copy of the drill.

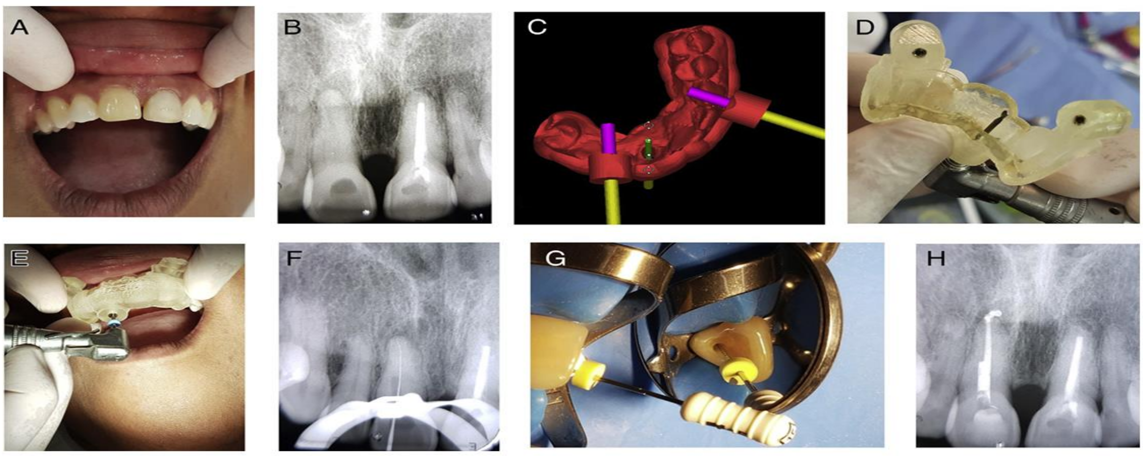

Figure 2. (*A*) The right maxillary central incisor discolored and yellowish. (*B*) Radiographic examination showing severe PCC. (*C* and *D*) The virtual and real bur positioned in the 3D template. (*E*) The template positioned in the mouth and guided dentin drilling. (*F* and *G*) Checking of the root canal length and (*H*) the final radiograph.

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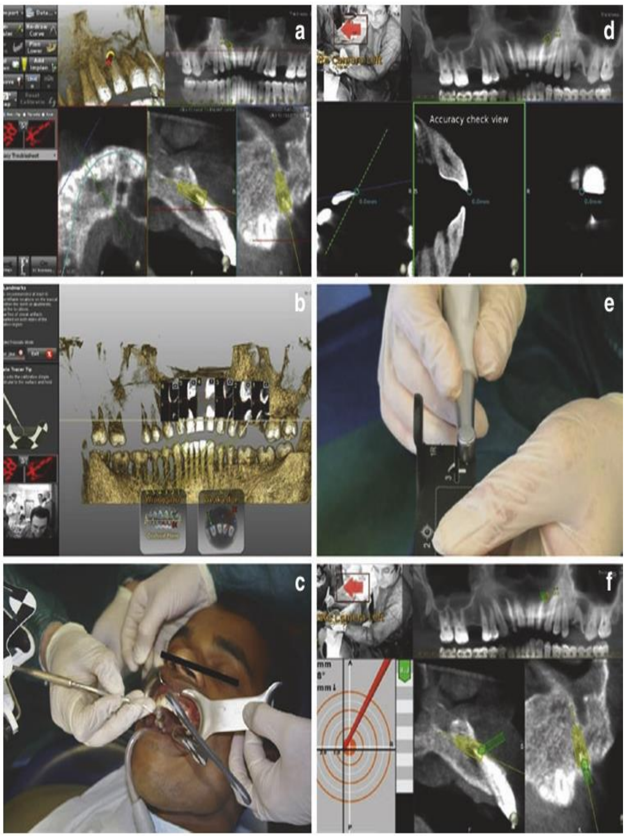
Case 2 – Dynamic Navigation for Apical Surgery [21]

[Gambarini G, Galli M, Stefanelli LV, Di Nardo D, Morese A, Seracchiani M, et al. Endodontic microsurgery using dynamic navigation system: a case report. *J Endod*. 2019;45(9):1173–1178. doi:10.1016/j.joen.2019.07.010.]

Gambarini et al. used dynamic navigation to perform a minimally invasive root-end resection on tooth 12 without crown removal. Real-time CBCT-guided drilling enabled precise access, accurate resection, and easy lesion removal, with intraoperative flexibility and enhanced visibility.



(a) Treatment planning using patient's previous CBCT scan. (b) Tracing: the system calibration phase is performed by selecting six different points on software reconstructions. (c) A fixed support is mounted on the patient's mouth, which can be recognized by the Navident's cameras, after which the six preselected points are traced using a tool that presents a support that can be recognized by the Navident to create matching between the CBCT scan and the patient's jaw. (d) Tracing is completed by an accuracy check view. (e) Before use, the handpiece and burs must be calibrated. (f) Drilling under dynamic guidance: the direction and the angulation of the bur during the surgical procedure can be checked on three different CBCT views.

Advantages Of Guided Endodontics:

- High precision and reproducibility
- Minimally invasive, preserving tooth integrity
- Reduces operator dependency
- Eliminates the need for dental operating microscopes
- Shortens treatment duration

Limitations Of Guided Endodontics:

- Ineffective in curved canals
- Limited visibility of fine structures in CBCT due to voxel resolution
- Restricted use in patients with limited mouth opening
- Imaging artifacts from metallic restorations
- Cost constraints for routine use

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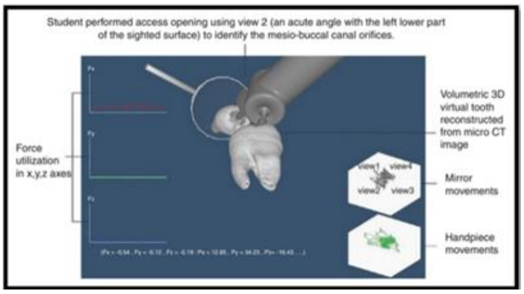
Future Trends of 3D Guidance in Dentistry

Technology	Description	Key Benefits	Clinical Example / Application
1. 3D Printing in Autotransplantation	CARP (Computer-Aided Rapid Prototyping) models are used to prepare the recipient site with a 3D printed replica of the donor tooth before surgery.	Minimizes surgical time, preserves periodontal ligament (PDL), improves outcomes.	Transplantation of tooth #17 into #18's socket using 3D models.[22]
2. Bioprinting	Stem cells from dental tissues are combined with scaffolds and growth factors (e.g., BMP-7, SDF-1) to bioprint tooth-like structures.	Enables biologically engineered teeth and regenerative therapies.	Tooth-shaped structures fabricated using a PCL/HA scaffold incorporated with SDF-1 and BMP-7.
3. 3D Printing in Smile Designing	Digital workflows using intraoral scanning, CAD software, and 3D printed templates to aid in anterior restorations.	Enhances smile harmony, natural aesthetics, and function.	Wong et al. and Rosati et al. used 3D models to plan smile designs.
4. Haptic Virtual Reality (VR)	VR simulators (e.g., Simodont®, VirTeaSy) provide tactile feedback for skill training in procedures like access prep and osteotomies.	Improves clinical skill development and confidence in complex cases.	Students using VR simulators for endodontic training and microsurgery.



A student performing endodontic access opening with haptic virtual reality system[23]

CONCLUSION-

Guided endodontics is an emerging and innovative technique with expanding applications. It is particularly beneficial in procedures such as locating root canals in teeth with pulp canal obliteration, performing microsurgical endodontics, and removing glass fiber posts during retreatment cases. This approach offers greater accuracy and safety compared to traditional methods, reduces treatment time for patients, and minimizes reliance on the clinician's experience

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