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TECHNIQUES

Dynamic navigation in endodontics

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Abstract
Dynamic navigation (DN) is a promising technology designed to guide the placement of drills/implants in real time, based on information generated from the patient's cone-beam computed tomography (CBCT). In endodontics, dynamic navigation is used for localization of calcified canals as well root-end resection surgeries. Treatment planning and surgery can be performed in the same appointment, based on data from patient's cone-beam computed tomography. This technology allows safe, minimal invasive and predictable access opening, osteotomy as well as root-end resection.

Keywords Dynamic navigation · CBCT · Calcified canal · Root-end resection · Guided endodontics · Navident

Quick reference/description

Preoperative planning and preparation dictate the outcome of any surgery as it facilitates the prediction of any challenges that may occur during surgery. A dynamic navigation system enables the operator to plan and prepare for surgery thereby, facilitating a well-planned surgery. Dynamic navigation is contributing greatly to the development in endodontic surgery. Advancements in targeted surgical navigation systems have improved the surgical manipulations and reduced the risk of iatrogenic damage.

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Indications

For potential use in endodontic procedures, such as:

- Root canal localization
- Trephination
- Endodontic surgery, such as root-end resection

Materials/instruments

- CBCT image
- Patient tracker (JawTracker, HeadTracker or NaviBite)
- Endodontic microscope
- Calibrated tracer (stylus pen or ball burnisher)
- Micron Tracker camera
- Handpiece attachment (DrillTag)
- Patient jaw attachment (JawTag)
- Optical tracking system
- Computer
- Navigation software
- Natural or fiducial markers
- Rubber dam
- Handpiece (slow speed, high speed or piezoelectric)
- Diamond bur (drill)
- Bone saw

Procedure

In dentistry, computer-navigated surgical and treatment techniques were first used for dental implant surgery. It also has potential uses in endodontics for root canal localization and trephination. Dynamic navigation for dental implant placement, also known as dynamic navigated surgery, is the placement of a drill or an implant with the use of a real-time computer navigated system depending on the data from the patient's cone-beam computed tomography (CBCT).

Principles of dynamic navigation

A dynamic navigation system strives to determine or localize a spatial position in association with its surroundings. Contemporary dynamic surgical navigation systems can identify a three-dimensional (3D) position of important structures using a stereoscopic camera with or without emitting infrared lights, such as reflective marker spheres. It facilitates real-time tracking of the marker spheres.

The requirements for a basic setup are a stereoscopic camera, a computer platform and screen, and a dedicated navigation software. In surgery, marker spheres are connected to the patient and to surgical instruments with reference arrays for facilitating a precise spatial localization and navigation in the operating room (OR). Every reference array has a minimum of 3 marker spheres. This aids the computer to estimate the position and orientation of every instrument. Firm attachment of the reference array to the patient (via a head clamp or in the bone) is essential for an appropriate virtual display and localization of the instrument on a computer screen. Intraoperative camera movements are possible as only the relative positions of tracked instruments to the tracked patient reference are relevant.

Dynamic navigation is mostly 'image-based' and needs the radiographic data of a patient. Understanding the dynamic navigation process requires knowledge of three terminologies.

- Image acquisition: includes obtaining a patient's radiographic data. CBCT imaging information (DICOM file) is used for navigation in dental treatments.
- Planning: preoperative planning of objects and areas of interest within the images is done to enrich the data sets.
- Registration: preoperative image data should be matched with the patient's current position through a registration process prior to drilling. This process develops an association between the 'actual' co-ordinate system according to the patient's reference array and the 'virtual' co-ordinate system of imaging information. Registration can utilize surface matching routines or be paired on the basis of points. It is also called as trace registration or tracing. It allows the clinician to virtually observe the current situation overlapped over the imaging data sets. Initiation of a dynamically navigated treatment can be done following a proper registration.

Contemporary orthopedic navigation systems are 'model based' and mostly work without data from external image sources. The navigation software estimates an individual model of patient anatomy depending on significant bone landmarks that are procured with a navigated instrument.

Different hospitals, surgical disciplines and surgeons have distinguished navigation requirements as per the workflow, required functionality and amount of flexibility. These surgical requirements can be accommodated by a wide variety of navigation platforms. Installation of navigation systems can be done permanently by mounting on the ceiling. It can have minimal to no footprint for reducing cable clutter. It can be mounted on mobile platforms for use in various ORs at varied times or for movement between hospitals for enhanced flexibility.

In dentistry, root canal localizations and implant positions can be designed and associated with reference points using the preoperative CBCT data and unique computer software. A dynamic navigation system is enabled via motion tracking technology that tracks the positions of the dental drill and the patient throughout the surgery by integrating the 3D images, surgical instruments and optical positioning devices.

Fig. 1 Workflow for Navident dynamic navigation system: the NAVIDENT workflow. **A** and **B** Scan: a preoperative CBCT scan of the custom TrueJaw model is acquired. Plan: the CBCT scan is imported into Navident, and the 3D virtual access trajectories are planned. The CBCT coronal and sagittal views of **C**–**F** tooth #25, **G**–**J** tooth #22, and **K**–**N** the second mesiobuccal canal of tooth #3 serving as a guide to plan nonsurgical virtual 3D access cavity/paths of 1.0-mm diameter. Trace: 6 landmarks (starting points for tracing) selected on the 3D rendered image on each of the **O** maxillary and **P** mandibular models on the screen. **Q** Clinical tracing on the jaw model with a tracer tool to register the CBCT scan to the model for the following navigation steps. Place (navigated access): the bur orientation and the drilling guided by "target" views on the computer screen for **R**–**T** tooth #25, **U**–**W** tooth #22, and **X**–**Z** the second mesiobuccal canal of tooth #3. The depth of the burs was monitored and indicated by the green bar of the depth gauge; the color changed from green to yellow when within 1 mm of the desired depth and from yellow to red when the correct depth was reached. (Courtesy: Sameer D Jain et al., License no: 5130881389143) ▶

The improved setup has an optical-motion-tracking system that provides feedback during surgery. This facilitates linking of the designed data to the real-time clinical scenario and the surgical equipment, and promotes instrument position traceability. This approach decreases surgical errors and is more accurate than manual or free-hand placement from the perspective of intervention outcomes. As per the findings of Bun San Chong et al., critical issues of implant surgery such as injury to crucial anatomic structures (adjacent tooth or nerve canal) can be decreased. This technique also provides flexibility to the surgeon especially when unplanned modifications are needed during the procedure.

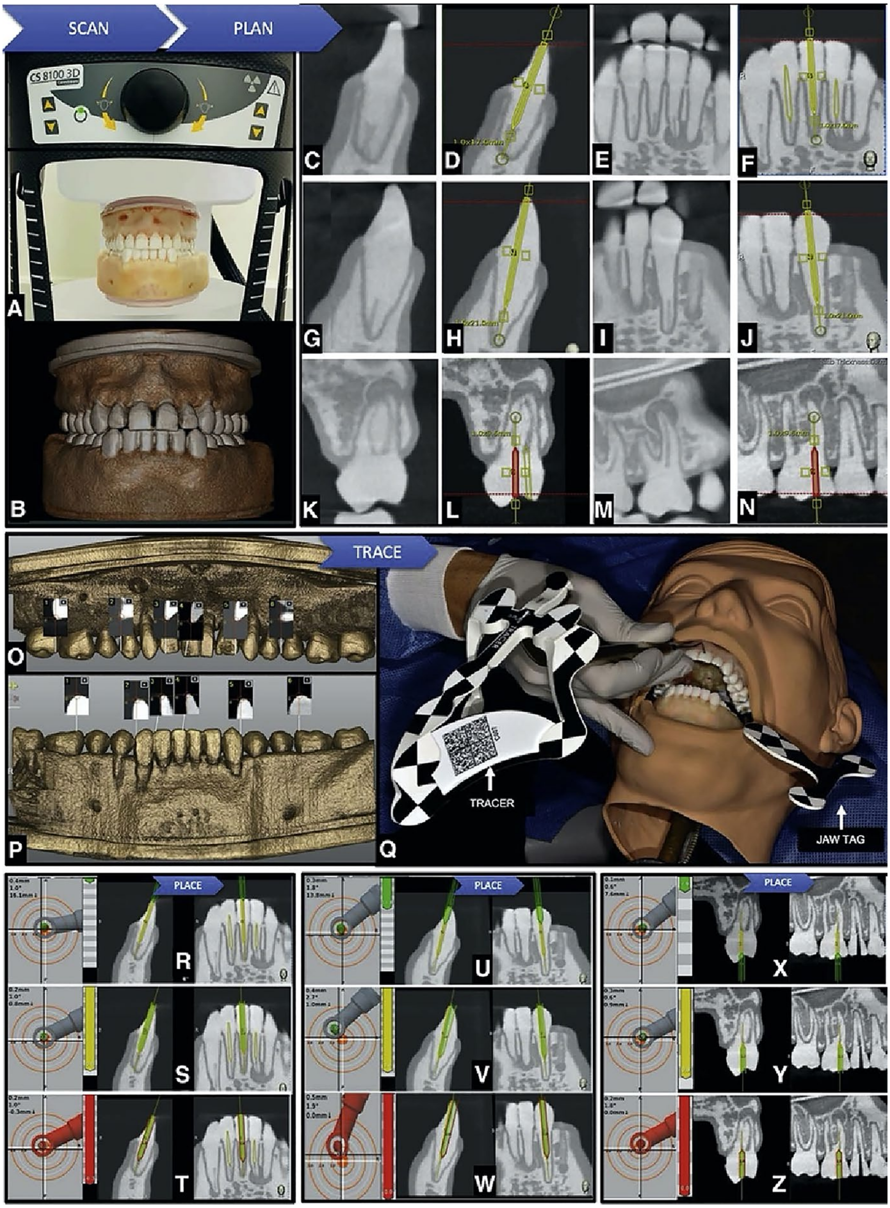
The modern dynamic navigation systems use optical technologies to track the handpiece and the patient, and display the images on the monitor. Active or passive tracking arrays are used in the optical systems. Active tracking arrays emit light that are tracked by stereocameras. While using passive tracking arrays, light emitted from a light source is reflected to the stereocameras.

A passive optical dynamic navigation system needs fiducial markers that are connected to the patient's arch during CBCT scanning. The device affixed to the fiducial markers permits arch registration to the cameras through array attachment. The array containing the fiducial markers is positioned extraorally. The handpiece also contains an array that facilitates triangulation in conjunction with the clip's fiducial markers for accurate navigation.

Workflow of dynamic navigation

For guiding the drill during surgery, navigation systems should meticulously map the drill tip to the CT image of the jaw that is utilized for implantation planning. The extraoral clip is affixed to the fiducial markers, while the sensors are affixed to the body of the handpiece. "Trace and Place" is the most commonly recommended workflow. This is achieved in chronological steps as follows (Fig. 1):

Scan: a preoperative CBCT scan should be obtained. Usually, a CBCT scan with limited field of view (FOV) is recommended for endodontic procedures. CBCT data is stored as a Digital Imaging and Communications in Medicine (DICOM) file. DICOM file is imported to dynamic navigation planning software, such as Navident (ClaroNav, Toronto, Canada).



Plan: CBCT data serves as a reference and guide to plan non-surgical or surgical endodontic treatments. For non-surgical root canal treatment, the entry point is inked at the incisal edge/occlusal table to the target point three dimensionally. The expected point of negotiation of calcified canal is the target point. For endodontic surgery, osteotomy cut are inked on the software three dimensionally. Clinicians can also decide level of root-end resection along with precise angle of root-end resection.

Trace Registration: CBCT images are matched with the teeth via a JawTracker or HeadTracker that is mounted on the patient, by registering the CBCT scan over the teeth or bone. For trace registration, a calibrated tracer (ball burnisher or stylus pen) that is tracked using a Micron Tracker camera is glided in a brushing motion along the tooth surface. The system simultaneously collects points along the path. The collected 'cloud of points' is matched with the outer surface of the teeth in the CBCT image in the best possible manner. Better accuracy can be achieved by tracing a minimum of 3 and a maximum of 6 teeth. An accuracy check should be done in the anteroposterior, occluso-gingival and latero-lateral directions to verify registration accuracy.

Calibration: the drill tip should be mapped to the DrillTag. Before initiating the surgery, drilling axis calibration is performed by placing the handpiece chuck over a pin in the JawTag. The drill tip site is calibrated after every drill change by touching a dimple on the calibrator.

Tracking (Mapping the DrillTag to the JawTag): it is a dynamic process which reveals real-time position of the drill intra-orally. It is performed throughout the surgery via the optical tracking system. Continuous tracking is critical to achieve planned therapeutic outcomes. The tracking camera must be kept at a position to facilitate a broad view of the operating field during treatment. A broad view of the surgical field can also be achieved using the extension arm of the navigation device.

Stepwise workflow.

a. A CBCT scan of the complete arch is obtained with a small field of view (FOV) and high resolution. The scan data is imported to the dynamic navigation system.
b. A CBCT file is used to plan the endodontic treatment in the dynamic navigation software. A virtual drill path is planned for non-surgical treatment. The virtual path is maintained as small as possible (no more than 1 mm). In case of endodontic microsurgery, the site and size of osteotomy is planned. Simultaneous planning of the angulation and level of root end resection can be done.
c. The patient tracker (HeadTracker or JawTracker) is installed. It should be kept within range of the camera tracking system. To prevent errors during dynamic navigation, use of an endodontic microscope is recommended.
d. Trace registration is used to register the CBCT image to the patient in any one of the following methods:

    i. Direct tracing on the CBCT scan
    ii. Superimposition or matching of an intra-oral scan with the CBCT scan
    iii. Using the NaviBite (when the tooth and its adjacent teeth have full coverage metallic restorations)

e. Placement of the patient tracker (JawTracker) and tracing should be done before rubber dam placement. During rubber dam isolation, ensure that the rubber dam and clamp do not exert force on the patient tracker.
f. The handpiece (piezoelectric, slow-speed or high-speed) and bur (drill) should be calibrated with a calibrator. Evaluation of registration accuracy should be done prior to drilling.
g. The plan should be followed during drilling, and the treatment should be completed. When multiple drills are to be utilized, each drill should be calibrated and checked for accuracy before using it intraorally.
h. Similar tracing and calibration should be done for endodontic microsurgery. A bone saw should be calibrated before use, and its dimension should also be calibrated for better accuracy. It is prevalent to perform the osteotomy and root-end resection simultaneously using a precise bone saw cut. In case of poor accuracy-check results, the CBCT image should be retraced followed by the treatment.

Dynamic navigation in non-surgical endodontic treatments

Appropriate implementation of non-surgical endodontic treatments should follow several rules. As per the requirements of modern endodontics, it is essential to sacrifice only a minimal amount of tooth material during any procedure. This is also known as the minimally invasive technique. The most conservative technique should be used to prepare the cavity borders, the access opening and the root canal orifices. However, the surgeon experiences several issues in actual clinical scenarios.

Commonly, exploration of a severely calcified and stenotic canal successfully requires removal of excessive tooth substance, which markedly weakens the tooth, impairs structural integrity and increases the risk of perforation. Hence, every effort should be made to aid the surgeon in preparing the cavity as minimally as possible, reducing iatrogenic harm, preserving structural integrity, while also fulfilling the expected requirements for gaining access. Therefore, static navigation is still commonly preferred among endodontists.

In dynamic navigation, after obtaining the patient's CBCT image, the DICOM files are imported to the Navident software followed by virtual planning of the drill path. Rubber dam is placed after registration and calibration. A small diamond bur is used to gain access into the tooth (Fig. 1). Dynamic navigation facilitates a minimally invasive and more precise access opening by preserving the pericervical dentin.

Dynamic navigation in surgical endodontics

Dynamic navigation is contributing greatly to development in endodontic surgery. Advancement in targeted surgical navigation systems has improved surgical manipulations and reduced the risk of iatrogenic damage.

Gambarini et al. used dynamic navigation for root-end resection of a tooth with sensitivity to percussion and periapical rarefaction (Fig. 2). Accurate and stepwise planning of the surgery is possible from the CBCT image. Modification of steps is also possible during surgery. The surgeon can verify and immediately correct any errors as the instruments are calibrated and closely monitored during surgery. A major challenge for root-end resection is differentiating the root apex from the surrounding bone. This issue can be resolved in a minimally invasive manner using navigation. Microsurgery also facilitates minimization and eventual elimination of the inclination of the root-end.

The ushering principle of radiation safety is As Low As Reasonably Achievable (ALARA). This principle means that clinician should outweigh benefits of CBCT exposure against risk of exposure. Case selection is always the key to success in guided endodontics. Guided endodontics is very useful technological advancement which can narrow the gap between novice and adept clinicians. With initial learning curve, it can help beginners in delivering extremely difficult treatments with more predictability.

Dynamic navigation in endodontic surgical procedures is considered progressive, because various potential sources of error such as radical osteotomy, inaccurate localization and injury to important anatomic structures can be avoided. Along with preoperative planning, immediate addressal of errors observed during surgery is also possible. It also helps to improve the operator's posture as they continue to concentrate on the display. It also has a fast-learning curve.

Advantages of dynamic navigation system

- CBCT scanning, surgical planning and surgery in a single appointment (subject to availability of a CBCT on site)
- Minimally invasive surgery resulting in decreased patient discomfort, decreased infection risk, and rapid recovery
- No unintentional or iatrogenic damage to adjacent anatomic structures
- Enhanced safety and predictability as guidance accuracy can be verified at any time
- Faster and simpler surgical planning
- Ability to view and alter the surgical plan during surgery
- Cost-effective
- Improved irrigation that decreases the risk of bone damage because of overheating
- No requirement of specialized equipment. It can work with any drill or implant system
- Guidance is provided even with limited interdental or interocclusal space
- Elimination of guidance failures owing to poorly fitting or fractured guides
- Improved ergonomics

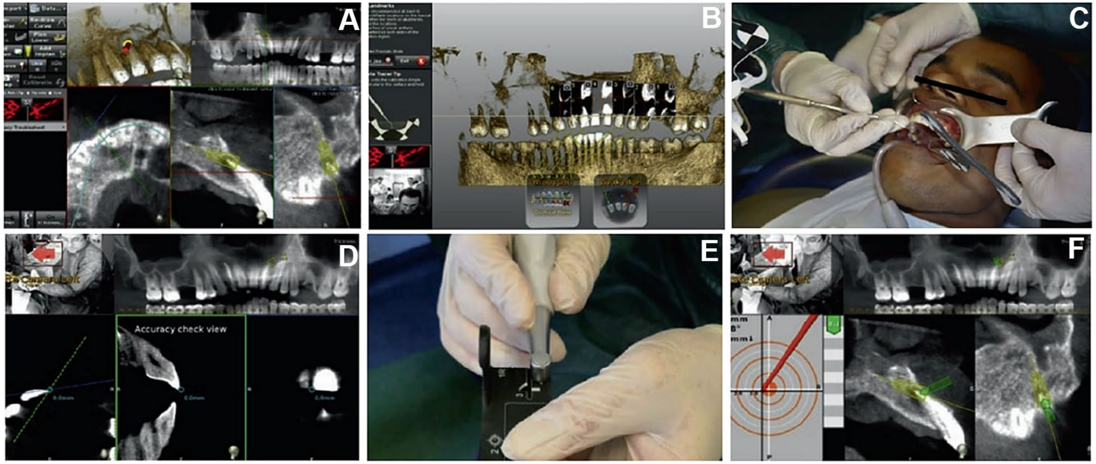


Fig.2 **a** Treatment planning using patient's CBCT scan. **b** Tracing, system calibration phase is performed by selecting 6 different points on software reconstructions. **c** Fixed support is mounted on patient's mouth that can be identified by the Navident cameras, after which the six preselected points are traced with a tool working as a support that can be recognized by the Navident for matching between the CBCT scan and the patient's jaw. **d** Tracing is completed by an accuracy check view. **e** Calibration of handpiece and burs before use. **f** Drilling under dynamic guidance. The direction and the angulation of bur during the surgery can be checked on 3 different CBCT views. (Courtesy: Gambarini et al., License no: 5130880615452)

Pitfalls and complications

- The initial cost of the navigation system, its updates and maintenance may not be feasible for the surgeon.
- Every dynamic navigation system has a unique planning software. Hence, other software cannot be used with it.
- Dynamic navigation in endodontics has a steep learning curve, which requires adequate clinical knowledge and learning from the operator.

Further reading

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