Dynamic Navigation System - A New Era in Endodontics

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Abstract: ***Dentists are in search of newer technologies that would enhance the accuracy of their diagnosis. The Endodontists, in their routine practice, face clinical situations such as calcified canals, multiple canals, difficulty in locating root canals and unusual canal anatomies. Many complexities associated with Endodontic treatment can be solved to a greater extent with the introduction of technologies such as the Endodontic microscope and Cone Beam Computed Tomography. There is a need for guiding the Endodontist to navigate the canal complexities. So, the Dynamic Navigation technology used in Implant placement has come to aid the Endodontists, this technology could be uniquely suited for the treatment of complex cases of both conventional non-surgical and surgical endodontics. By creating a similar application with the Trace Registration method which allows the dentist to register the Cone Beam Computed Tomography (CBCT) onto the patient by selecting three to six radiographically distinct, accessible landmarks on the screen, then tracing them in the patient's mouth. This Real-time (dynamic) navigation is a valuable alternative whereby one can avoid the fabrication of a stereolithographic template resulting in less expensive treatment. This system will be a beneficial adjunct for successfully treating root canal complexities safely and predictably. In addition, this technology can potentially be used to make smaller, less invasive access preparations and can be an effective option in apical surgery also. Hence this non-invasive, digitized, dynamic navigation system will be a promising digital method in times to come. This review article enlightens on the dynamic navigation system in Endodontics.***

Keywords: Dynamic Navigation system, Navigated access cavity preparation, Cone Beam Computed Tomography.

1. Introduction

Innovation and advancements will step up the quality of life by implementing the futuristic needs in the fields of Science, Medicine and Dentistry. In the field of Dentistry, it is a known and proven fact that root canal treatment can successfully retain the compromised teeth which were fractured, carious, or traumatised over a period of time. [1, 2] The Endodontic treatment can be a complicated procedure in the hands of an inexperienced operator while treating highly calcified root canals, root canal curvatures and the presence of developmental anomalies like dens invaginatus, radix entomolaris, paramolaris. All these add more difficulties leading to iatrogenic errors. So, the operator must not only be aware of the tooth anatomy and pathology, but also possess the clinical skills required to treat the particular tooth adequately. The skill of the operator is weighed more in tackling such iatrogenic errors, but it is inevitable even in the hands of an experienced operator to commit errors in the small three-dimensional root canal space. Whenever there is a need to explore specific sites very accurately and techniques to prevent such iatrogenic errors, Endodontist prefer a technological advancement with sound knowledge about the internal anatomy of root canal and thereby combining, correlating with three-dimensional tooth morphology. For achieving this, there is a need for synchronizing the (CBCT) Cone Beam Computed Tomography three-dimensional data with the intraoral surface morphology of the patient by utilising dynamic navigation software technology. The complete understanding of internal anatomy of tooth and tooth morphology by CBCT, and combining all the available technologies in the field of dentistry like the three-dimensional surface scanning software, Stereoscopic motion tracking cameras and sensors with position indicating system in combination with Dynamic navigation software helps the clinician to navigate into intricate root canal spaces accurately. This system also has the efficacy of reducing iatrogenic errors compared to a regular conventional procedure. Hence, this review article highlights about the Dynamic Navigation System, its basic principle, usage and application in the field of Endodontics.

Evolution of Dynamic Navigation System:
Dynamic navigation (DN) has improved the process by providing surgeons a real-time navigation tool to improve the accuracy of treatment. Currently, DN is used by many medical specialties, including ophthalmology, otolaryngology, orthopaedics, vascular surgery, neurosurgery, and surgical oncology[3]. These specialties routinely use DN to perform simple and complex procedures with increased accuracy and precision[4]. In the field of dentistry, DN historically has been used primarily by oral and maxillofacial surgeons. The medical DN systems used were designed primarily for craniomaxillofacial based procedures, such as orthognathic, trauma, pathology reconstructive procedures and locating foreign bodies within the head and neck. It was initially utilised by the Craniofacial surgeons and then undertaken by Dentists for accurate placement of the dental implants in the field of Implantology. [5, 6] Dynamic Navigation system (DNS) is a promising technique with a high degree of predictability and a low risk of iatrogenic damage. So, whenever there is a need to explore specific sites very accurately, dynamic navigation would be of immense help. The Dynamic Navigation technology could be uniquely suited for the treatment of complex cases of both conventional non-surgical and surgical endodontics[7]. So, this system will be a beneficial adjunct for successfully treating root canal complexities, safely and predictably, because this technology combines the coordinates of the available DICOM data from CBCT and surface topographical scans fed into new software applications in a seamless manner. In addition, this technology can aid in minimally invasive dentistry to prepare conservative access cavity designs and can be an effective option in creating osteotomy in periapical microsurgery also. Dynamic Guidance Systems

for implant placement that have been developed include RoboDent (GmbH, Berlin, Germany), X-Guide (X-Nav Technologies, Lansdale, Pennsylvania), Image Guided Implantology (Image Navigation Fort Lee, New Jersey, USA) and Navident (ClaroNav, Toronto, Ontario, Canada). These models can be utilised for Endodontic procedures such as Access cavity preparation and Surgical procedures like Osteotomy and cortical trephination[8].

Technical Steps in Dynamic Navigation System (DNS):

The workflow (Fig: 2) in using DNS follows systematic procedural steps clinically. The technical procedures consist of following steps.

Step 1: Cone Beam Computed Tomography (CBCT)
Step 2: Cone Beam Computed Tomography (CBCT) treatment planning
Step 3: Setting up of Head Tag, Jaw Tag and Stereoscope motion sensing camera for Jaw Tracking
Step 4: Calibration of instruments
Step 5: Verification and pilot drilling
Step 6: Dynamic Navigated Endodontic Procedures

Figure 1: (a) Drill Tag mounted on handpiece, (b) Drill Calibrator calibrating the handpiece bur, (c) Jaw Tag with attachment clip, (d) Jaw Tracker for trace registration, (e) Head Tag for maxillary arch, (f) Stereoscopic motion sensing cameras with light present overhead with computer displaying the position through dynamic navigation software.

Step 1: Cone Beam Computed Tomography (CBCT)

The computed tomography (CT) scan is taken with the fiducial clip seated properly in the patient's mouth without any movement or rocking of the fiducial clip. The tracker arm attachment section of the fiducial clip should be on the buccal or cheek side of the patient. The fiducial clip must be placed on the arch without interference when X-Guide system is used (X-Nav Technologies, Lansdale, Pennsylvania). The fiducial clip is placed in a hot water bath at a temperature of 140 F to 160 F (60˚C–71˚C) for approximately three to five minutes. When the thermoplastic fiducial clip is clear, it is ready to be used. The fiducial clip should cool for approximately for one minute to reach a surface temperature less than 104F (40˚C). The fiducial clip for X-Guide system is placed on three teeth, ensuring an equal distance on the buccal and lingual sides, with the tracker arm positioned on the buccal side. Once an adequate impression is taken, the fiducial clip is removed and then placed in a cold water bath. The fiducial clip should not have any mobility when seated. If there are short clinical crowns or teeth without undercuts, composite can be added to the buccal and occlusal surfaces of the associated teeth to help create immobile fiducial clip insertion. Image acquisition includes obtaining 3-D files, usually a CBCT in a Digital Imaging and Communications in Medicine format (. dicom). The field of view of the CBCT or CT should include the endodontic site and all fiducials. The scan is obtained with the plane of occlusion parallel to floor. For dental treatment planning purposes, a cotton roll or radiolucent material is placed between the dentition and the buccal/labial mucosa an air creating contrast zone. This allows the soft tissue in the region of the free gingival margin to be visualized on the CBCT. Additionally, the use of an intraoral scanner (IOS) is made for the both the arches. These are not volumetric images; IOS images are a 3-D surface images of the patients' dentition that can be saved for later use for planning of provisional fabrication.

Step 2: Cone Beam Computed Tomography (CBCT) treatment planning

The dentist will select specific points on the CBCT during treatment planning. Treatment planning using the patient's previous CBCT scan is done. Once the images are acquired and stored, they are loaded into treatment planning software. There are numerous software packages available, but some key features should be present related to image processing and analysis. The software should be able to import and export generic file formats (. dicom and. stl), superimpose the 3-D files, perform dual scan. dicom superimposition and be able to export the images in a common co-ordinate system as an individual or merged item. When these clean. stl images are superimposed on the CBCT data, the combined images allow the Endodontist team to plan, with the osseous, dental, and soft tissue structures clearly visible along with the patient's occlusion. When starting to plan on the DN software, a panoramic curve for the arch requiring treatment is developed on the axial plane of the patient's scan. On the mandible, the inferior alveolar nerve also can be identified and marked. Merger of the patient's scan and the IOS image is performed, ensuring there are multiple area of coordination between the images. The planning of endodontic treatment should be restoratively driven. This starts with evaluating the occlusion and placing the restorative envelope of the virtual teeth in the proper occlusal position. This can be done using virtual implant crowns available in the DN software or to use a prosthetic software to plan the restorations. The plan is then exported from the prosthetic software and imported as a. stl file into the DN software.

Step 3: Setting up of Head Tag, Jaw Tag and Stereoscope motion sensing camera for Jaw Tracking

The overall system is a combination of motion tracking devices. They are fitted over patient's head which is similar to headphones type called the Head Tag (fig: 1e) and Jaw-Tag (fig: 1c) which is inserted like a lip clip. The Jaw Tracker (fig: 1d) helps in registering the constant landmarks intraorally, acts as a reference point in the CBCT scan of the patient, and also synchronizes the three-dimensional volumetric data with patient surface scan obtained by Jaw tracker. The complete motions and actions are captured with the help of the overhead Stereoscope Motion tracking Camera (fig: 1f) and fed inside the software of DNS connected to a navigation software computer. The system calibration phase is performed by selecting six different points on software reconstructions in Navident System. A fixed support is mounted on the patient's mouth, that can be recognized by the Navident's cameras, after which the 6 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. The Trace Registration method allows the dentist to register the CBCT scan to the patient by selecting three to six radiographically distinct, accessible landmarks on the screen, then tracing them in the patient's mouth[9]. This method eliminates the need for a special second scan to be taken with a metallic fiducial-marker affixed to the jaw with a thermoplastic stent. reducing the exposure to radiation, it reduces the chance for errors caused by stent dislocation during the scan and allows for the use of a small volume CBCT. As a consequence, it also minimizes time and cost to the procedure. After the patient tracker is placed the patient will be registered by touching those points with the calibrated probe. Patient will have a potentially cumbersome tracking arms attached to their mouth. The complete motions and actions are captured with the help of the overhead Stereoscope Motion tracking Camera and fed inside the software of DNS connected with a computer.

Step 4: Calibration of instruments

The Drill Calibrator (fig: 1b) helps in calibration of different size of burs used during preparation. DNS can calibrate and track both high-speed and low-speed driven burs. The calibrations of rotary instruments, endodontic explorer are also possible, enabling the clinician with the use of any such instruments for access cavity preparation and surgical procedures[8]. The Calibrator is a multi-tool calibration device. The quick calibration process done using this tool is used for determining the drill tip position and location in relation to the optical tracking tag installed on the handpiece. This way the navigation system can adapt to the particular angulation and length of the drill to be used, when preparing the access cavity and have it represented correctly on the navigation screen. [10] Each time a bur is changed in the handpiece, it should be recalibrated by the operator.

Step 5: Verification and pilot drilling

After calibrating the handpiece and just prior to access cavity, the operator is prompted to a perform a "sanity check" step, where the system's accuracy is verified. The Drill-Tag (fig: 1a) which synchronizes the movement of handpiece with DNS software. This is done by touching with the drill-tip on distinct rigid landmarks (such as teeth cusps) in the treated jaw, and comparing the physical drill's location to its on-screen position representation (in light blue). This check can be repeated at any time during the procedure[9, 11]. It is important to always confirm the accuracy of the tracking system by performing frequent system checks.

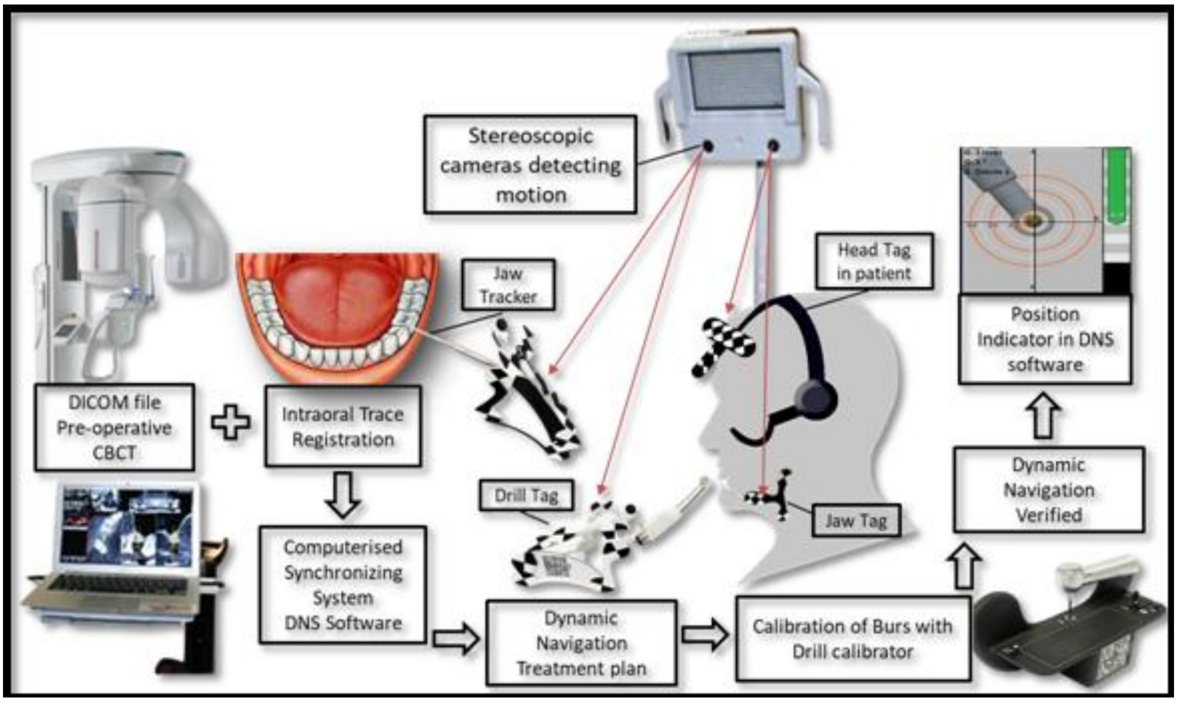

Figure 2: Workflow and setup for Dynamic Navigation System

Anatomical landmarks on the patient are touched with the instruments. The doctor then visually confirms that the radiographic landmarks on the screen are exactly correlating. The operator looks at the screen as the drill is positioned over the surgical site. The navigation system screen allows viewing of a virtual drill with demonstration of the depth in tenths of a millimetre, and angular deviation of the drill bit axis from the planned access cavity preparation axis to the tenths of a degree.

The tip of the drill, a blue dot, is positioned over the target to indicate ideal planned platform position. The top of the drill position a small circle is then centred over the blue dot to indicate ideal planned angle. Depth is indicated by colour, yellow, green the red in X-Dent system. Navident system will have an orange with white circles in target point shape and the centre point is denoted with a cross mark. The planned depth is always at the position on the target. The assistant is in charge of suctioning and looking into the surgical field to notify the operator of any irregularities such as lack of irrigation or grossly off-positioned drill placement.

Step 6: Dynamic Navigated Endodontic Procedures:

Dynamically Guided Endodontic Access Cavity Preparation:
Once the handpiece and the bur are calibrated, Navident dynamically projects on the screen, the actual place and position where to initiate the access. During the access cavity preparation, the depth indicator changes in colour from green to yellow when the drill is 0.5mm from the targeted depth. The yellow will turn to red indicating when to stop the depth of the access cavity. It also indicates where the tip of the bur is present at real time, guiding the operator to the predetermined place to locate the calcified, additional canals faster and more accurately during the procedure[12]. The navigation software enhances on the exact path as the clinician when trying to locate the calcified canals very accurately. The walls of the access cavities prepared with the computer-aided Dynamic Navigation System are narrow and parallel. With the aid of this technology, conservative accesses can be made which is similar to the concept of Minimally Invasive Dentistry. Preservation and conservation of dentin is one of the main objectives when performing any dental procedure. In addition, this technology will allow for the location of canals that otherwise could not be detected and negotiated with more traditional techniques[1314].

Dynamically Guided Endodontic Microsurgery Approach:
The endodontic microsurgery includes osteotomy, apicectomy and root end preparation. The ability to differentiate the root tip from the underlying bone is a significant clinical issue during osteotomy. It is difficult to accurately identify the root tip using traditional methods. [15] Finding the apex if the apical lesion has not fenestrated the buccal bone will be difficult. The sensitivity of the system enables the operator to accurately identify the root tip in a recent case report by Gambarini et al.; the osteotomy and root-end resection were completed easily and rapidly with a minimally invasive procedure without iatrogenic errors. This allowed for proper apical curettage and retrograde cavity preparation[16]. The bur can be precisely angulated to cut the root end with a 10° bevel angle, and the cutting was visualized and controlled in real time on the display in dynamic navigation system. The shorter surgical instruments can be easily navigated and can be used more effectively in posterior regions. Thus, it increases the accessibility in patients with limited openings[7]. Dynamic Navigation system has proved to be a reliable and simple method for achieving this aim while minimizing the size of the osteotomy[17].

Pros and Cons of DNS:

Advantages of Dynamic Navigation Systems:

- Straight forward procedure and reduces errors, more accurate.
- It allows clinicians to manually reach targeted site, by guiding its way allowing an Endodontist to accurately target the access cavity in association with CBCT.
- They are similar to static guides in surgical procedures of implant placement and Guided Endodontic access cavity preparation except that there is no use of customised stent [18].
- It has the ability to replace the rigid stent for guiding. Ultimately, the cost of fabrication of template is cut down while using the dynamic navigation system.
- The mean 2D horizontal deviation from the canal orifice was 0.9 mm. The mean 3D deviation from the canal orifice was 1.3 mm. The mean 3D angular deviation was 1.7 degrees.
- Dynamically navigated access preparation was significantly faster than the freehand technique in both arches. The average drilling time was 57.8 seconds with significant dependence on the canal orifice depth, tooth type, and jaw. [19]
- The Dynamic Navigation's high precision minimises the possible risk of injuries to adjacent vital anatomical structures, including nerves and neighbouring teeth, increases intraoperative safety, leading to significant improvements in the efficiency of treatment.
- The flexibility given to the user is a big advantage of the Dynamic Navigation technology.
- Adjustments to the surgical schedule can be made at all times depending on the clinical condition.
- Preparing the surgery or other potential dental operations virtually ahead of time allows for a thoroughly planned operation. So that, the patient chair time decreased by enhancing the productivity of dentists. [20]
- This technique has the potential to be applied in Endodontics for access cavity preparation especially in cases with severe canal calcification.
- In addition, it can be utilized in cases with developmental malformations such as Dens Invaginatus/ Evaginatus, fiber post removal, and even for performing a conservative osteotomy and root end resection in endodontic microsurgery.
- It can be used with an educational interest for finding of root canals. It is well-known that even with the use of the Dental Operating Microscope (DOM) in negotiating extremely calcified root canals, there is still the risk of

deviation, perforation, or tooth structure loss and over-preparation of the root canal space.
- Ergonomically, DNS allows the operator to look at the screen more so than inside the mouth, decreasing the need to bend the back or neck for a prolonged period.

Dynamic Navigation System (DNS) has the potential to provide important advantages over the static approach. Advantages include:

- The ability to do the entire procedure (CBCT, planning and treatment) in a single appointment.
- Its increased safety and predictability by verifying the guidance accuracy live during the procedure.
- Simple and faster planning, with improved irrigation, reducing the risk of tooth structure damage due to overheating.
- Guided approach is possible with limited interocclusal or interdental space since a physical template is not necessary.
- Application of augmented reality devices and head-mounted displays in addition to DNS systems can be helpful in transferring and overlaying the virtual plan on the patient jaw and teeth.
- This can provide the benefit of not losing track of the operation/treatment field and the possibility of using a 3D-microscope for magnification.
- Static and Dynamic computer aided navigation techniques are highly accurate in locating root canal systems in order to perform endodontic access cavities and microsurgeries[21].

The Disadvantages of Dynamic Navigation Systems includes:
- Expensive equipment procurement, upgrades, and device repairs.
- Multiple recalibrations needed during a single operation.
- The CBCT scan resolution can influence virtual planning of the preparation of an endodontic access or an osteotomy. Need for a wider field of view CBCT.
- Clinician's inability to operate through the dental operating microscope-requirement to look at the monitor when doing the guided procedure.
- Heavy and cumbersome sensors on both the handpiece and the patient which makes it uncomfortable for routine use.
- Some companies have developed ideas like laser printing of the dynamic reference frames on the handpiece body or some modifications in the attachments design to make it easier to grip.
- The relatively high cost of the machine and the extra charge for the X-clip/procedure can be another limiting factor in the widespread use of this technology.

Applications of Dynamic Navigation System:
- Endodontic surgical osteotomy
- Endodontic access cavity preparation
- Apicectomy
- Endodontic retrograde root end cavity preparation
- Post and core placement
- Removal of post and core system
- Endodontic retreatment [22]

Limitations Encountered During Operation:

- The difficulties faced by the operator while using this system are establishing stable reference points intraorally and matching the points with patient's actual CBCT scan.
- The minute alteration in position of the patient's head would disturb the file synchronization. During viewing of the device, the user must maintain the right orientation and angle to the handpiece.
- The position of the overhead stereoscopic motion tracker camera influences the overall tracking since orientation plays a main role.
- Burs utilised has to be recalibrated individually with Drill Calibrator before use for dimensional accuracy with position inside tooth.

New technology has its own learning curve. In order to achieve skill, motor control, eye hand co-ordination, manual dexterity, system awareness and continuing practice is required. In a clinical trial, the learning curve for dynamic navigation was significant as the level of expertise of a surgeon seems to increase the result[13]. However, if this proves to reduce significant operation time and prevent iatrogenic mishaps in the clinical setting, the cost would be well justified. With the emergence of advanced technologies such as augmented reality and design modifications and updates, several limitations of using this technology can be addressed in the near future.

2. Conclusion

The evolution from analog 2-D imaging and diagnostics to digital 3-D imaging and diagnostics has led to increased understanding of the complex nature of Endodontic root canal system. The increased utilization of these digital 3-D diagnostic and therapeutic modalities allows the Endodontist to overcome the limitations of freehand access cavity preparation in complicated situations. Dynamic Navigation is a promising technique with a high degree of predictability and a low risk of iatrogenic damage. Hence, quality treatment can be performed with the minimal invasiveness with a predetermined prognostic factor for the patients.

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