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Original Research Paper

Endodontics

A REVIEW OF GUIDED ENDODONTICS AND ITS APPLICATIONS

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ABSTRACT Guided Endodontics has emerged as a novel concept in the field of endodontics with a multitude of applications for cases with difficulties as well as routine procedures. Its applications arrays from static guided access and guided surgery to dynamic navigation. Advent of CBCT and 3D printing in dentistry coupled with virtual planning softwares has revolutionized the field of guided endodontics. It is particularly of immense use for root canal therapy in cases of pulp canal obliteration, complex root canal anatomies, developmental anomalies and non-surgical re treatment cases. It preserves Peri Cervical Dentin and minimizes inadvertent loss of tooth structure and iatrogenic errors and saves clinical chair-side time. It can be utilized for endodontic microsurgery to improve accuracy via minimal invasion and preventing damage to adjacent vital structures. The concept of dynamic navigation allows a real time view of the operative procedure, improving precision and minimizing clinical errors. This review presents a detailed insight into the virtual planning, workflow and applications of guided endodontics.

KEYWORDS : Guided endodontics, Static guided access, Guided endodontic surgery, Dynamic navigation, Microguided endodontic, Microguided access, Guided endodontic microsurgery.

INTRODUCTION

Newer technological advancements over the past few decades have significantly impacted the medical field. There are numerous examples of technological advances in the fields of both medicine and dentistry, where its benefits to patients have been clearly evident and hence rapidly integrated into our daily clinical practice. It is now generally accepted that guided surgery or navigation in operative and surgical dentistry will be the next impactful innovation to join this list.[1]

Navigation in dentistry is also known as Guided Dentistry. It is emerging as one of the most reliable representatives of digital technology as it continues to transform operative and surgical interventions into safer, predictable, and less invasive procedures. Utilizing a navigation system for various dental procedures allows the clinician to achieve ideal placements for implants or gaining straight line access to root canals with minimal tooth substance loss.

Guided dentistry gives accurate outcomes for access cavity designs and access to complex root canal anatomies, direct access to peri-radicular region in cases of periapical surgery and implant placement while preserving the vital anatomical structure adjacent to the area of interest and preserving tooth substance as well as bone. It would also help the clinician to reduce chair-side time of the patient and reduce the discomfort experienced by the patient.

Concept of Digital Dentistry

In a quest for safer, less invasive, and predictable treatment, the concept of digital dentistry came into play. In modern digital dentistry, the four basic phases of work are image acquisition, data preparation or processing, the production, and the clinical application on patients.

Data or image acquisition employs digital devices such as digital cameras, intraoral scanners, extraoral scanners, face scanners, CBCT, and micro-CT with low radiation dose. The optical impression is now replacing the classic method of recording impression with tray and impression materials. Optimization of this data helps in accurate visualization of the anatomy and morphology of dento-gingival structures.

The development of specific softwares has made it possible to virtually plan the clinical stages, evaluating probable errors or accurately predicting the amount of wear in tooth preparation, direction and angulation of access preparation, length of an implant, tooth movement pattern, etc. Thus, treatment by trial and operative procedures error may be avoided, and it is planned more efficiently and with lesser clinical time.[2]

The 3D printing technology (Stereolithography technique) allows the production of endodontic guides. The three-dimensional design of the guide developed by the digital planning software is also exported in STL format.

Currently, endodontic guides are printed in light-curing liquid resin with direct light processing technology (DLP - Direct Light Processing) due to the better cost-benefit ratio. In fact, the role of 3D imaging, printing and virtual planning for successful management of the various endodontic procedures is exceptional.[3] Accuracy of access cavity preparation with 3D-printed endodontic guides is best described by its angular deviation of the canal access ability. In addition to this, 3D guided surgical endodontics in combination with haptic stimulators and 3D imaging (CBCT) has helped to successfully carry out root resection procedures. Various endodontic failures have been treated successfully with the 3D technology with best accuracy and comfort and reduced working time.

Concept of Minimally Invasive Dentistry

Minimally Invasive Dentistry is the application of "a systematic respect for the original tissue." This implies that the dental profession recognizes that an artifact is of less biological value than the original healthy tissue.

Access cavity preparation is considered a fundamental step in orthograde endodontic treatment, which is crucial for the results, stability, and longevity of the tooth. Straight-line access to the orifices of the root canals is recommended, but recently, contracted endodontic cavities (CECs) have come up from the concept of minimally invasive dentistry.

Access cavity designs that include both the marginal ridges, tend to reduce cuspal stiffness by 63%, therefore access cavities should be kept as conservative as possible. They have been presented as an alternative to traditional endodontic access cavities (TECs), designed for maximum preservation of the healthy coronal, cervical, and radicular tooth structure during the endodontic treatment.

Peri-Cervical dentin (PCD) is defined as the dentin near the alveolar crest. This critical zone, roughly 4 mm coronal to the crestal bone and extending 4 mm apical to crestal bone, is crucial for load transfer from the occlusal table to the root.[1] In conventional deroofing process, much of PCD is lost, which reduces fracture resistance of the tooth. There is a decrease of fracture resistance by 20-30 percent with loss of 1mm internal PCD from inside walls of access preparation which was quite less as compared to the loss of walls, where there is a decrease of fracture resistance by 40-50 percent with complete loss of PCD of any of the walls.[4]

With enlargement of the access cavity, the stress on the pericervical dentin increases dramatically. In the contracted endodontic cavity (CEC) preparation, the chamber roof is kept as clean as possible. With the routine use of magnification for endodontics, access need not necessarily mean straight-line visibility of all the canal orifices. Guided endodontics helps in preservation of PCD and offers the most conservative approach for cases with high difficulty level such as calcified canals and anatomical anomalies.

Guided surgery in cases of separated instrument beyond the apex or cases where periapical lesion is not perforating or large enough to necessitate frank osteotomy, or where vital structures pass near to the region of osteotomy; helps in preserving bone tissue, vital structures and at the same time gives direct, conservative and accurate access to the area of instrumentation. Manual surgery would result in improper angulations, resulting in tissue substance loss which is detrimental to surgical healing. Guided conservative approach overcomes this issue.

Need For 3D Guided Endodontics

1. Management of Calcified Canals

Pulp canal obliteration or calcification is characterized by the deposition of hard tissue within the root canal space. In anterior teeth, it occurs commonly as a result of concussion, subluxation, or luxation injuries. In elderly patients, the ongoing deposition of both secondary and potential tertiary dentin may reduce the root canal space as well.[10, 11] External injuries resulting in tertiary dentin can be caused by caries, wear, irritation from preparations, and/or subsequent filling materials. The deposition starts from the coronal part of the root canal while the apical portion maybe patent.

Following the conventional methods of access cavity preparation may lead to excessive loss of tooth structure in terms of peri cervical dentin which is extremely crucial for the strength of Endodontically treated teeth and searching for canal orifices may even lead to iatrogenic perforation. Pulp canal obliteration is implicated in up to 75% of perforations during attempted location and negotiation of calcified canals.

In cases of calcified canals, technical failures such as root perforation, fracture of a file or inaccessible root canals can occur in one third of the cases, which led to significantly reduced healing rates after root canal treatment.[7] Even successful negotiation of an obliterated root canal might be associated with substantial loss of hard tissue particularly in the cervical region, which is prone to root fracture.

Guided endodontics can deliver more predictable treatment outcomes compared to conventional treatment strategies. This novel concept could help clinicians avoid unnecessary removal of tissue, avoiding complications and therefore, improving the prognosis of treatment.[8] Guided approach can be static or dynamic.

2. Endodontic Surgery

Endodontic microsurgery requires a targeted osteotomy and root end resection based upon anatomic landmarks and preoperative X-Ray or CBCT measurements. The use of a surgical guide yielded a mean distance of 0.79 mm from the apex, in contrast to the freehand osteotomies with a mean distance of 2.27 mm reported by Pinsky et al. [9] The use of guides for periapical surgery reduces the diameter of the osteotomy to a size slightly larger than the length of the resection.

Moreover, in cases of periapical surgery in the posterior region or where the proximity to vital structures deems it difficult to operate, 3D printed stents can mitigate risk through avoiding encroachment upon neurovascular structures and adjacent teeth. When periapical surgery is indicated to remove fractured instrument beyond the apex or extrusion of gutta percha where non-surgical approach cannot be taken due to obstructions, use of guided surgery will conserve the cortical bone and minimise the instrumentation required and result in shorter healing time, decreased postoperative pain, and improved outcomes.

3. Root Canal Variations

Complex anatomies and variations in the root canal systems makes it difficult to access all the canals which are times narrow or calcified and inaccessible due to deep apical splitting. Conventional instrumentation may lead to strip perforation or zipping. Guided endodontics helps in accessing such anatomy without causing damage due to iatrogenic errors.

4. Non-Surgical Root Canal Re-Treatment

Occasionally, even very skilled clinicians can create a deviation from the original path of a root canal when treating teeth with complex anatomies and severe calcifications. Negotiating ledges or gaining access to the original trajectory from the transportation of the canal becomes tiresome. In such cases, the guided endodontic technique favours the resumption of the original anatomical trajectory after conventional endodontic treatment without success in a severely calcified canal.

5. Developmental Anomalies

In cases of developmental anomalies, the complex anatomy of the pulp canal does not permit a straight-line access to the clinician. Guided access can be put to use for accurate access to the pulp space. In cases of dens invaginatus or dentin dysplasia where preserving the remaining tooth structure is of utmost importance, owing to the thin radicular dentin walls, it will help in preserving more amount of PCD, than conventional access preparation, thereby increasing the fracture resistance of the Endodontically treated teeth.

Role Of CBCT In Endodontics

The faithful copy of the internal anatomy provided by the advancement of CBCT devices and software, associated with the digital resources of 3D planning and printing, enabled the advent of guided endodontics. The applications of CBCT have made it possible to visualize the dentition, the maxillofacial skeleton, and the relationship of anatomic structures in three dimensions. The image formation process consists of three stages:

- Acquisition stage
- Reconstruction stage
- Image display

In general, CBCT is categorized into large, medium and limited-volume units based on the size of their "field of view." The size of the FOV describes the scan volume of CBCT machines, determining the extent of anatomy included. To the extent practical, FOV should only slightly exceed the dimensions of the anatomy of interest.

Small-volume CBCT of FOV <8 cm is used to scan a range from a sextant or a quadrant to one jaw only. Generally, the smaller the FOV, the lower the dose associated with the scan. Smaller scan volumes generally produce higher-resolution images. Because endodontics relies on detecting small alterations such as disruptions in the periodontal ligament space, it is desirable that the optimal resolution of any CBCT imaging system used in endodontics does not exceed 200 μm, which is the average width of the periodontal ligament space.[13]

Applications of CBCT in Guided Endodontics

- CBCT reconstructions are important in assessing teeth with an unusual root morphology in terms of number of roots, dilacerated teeth, and dens in dente.
- CBCT imaging showed the tendency to more accurately identify fractured files, cast post deviations, and perforations compared with radiographs. Thus, for virtual path planning for re-treatment cases.
- CBCT data reveals additional relevant information about root canal morphology and neighbouring anatomic structures, the relationship of a periapical lesion with a root, and the thickness of the cortical and cancellous bone plates, which cannot be readily obtained from conventional radiological views. Hence, CBCT imaging has been recommended for endodontic surgery treatment planning.[14]

Limitations of CBCT Imaging

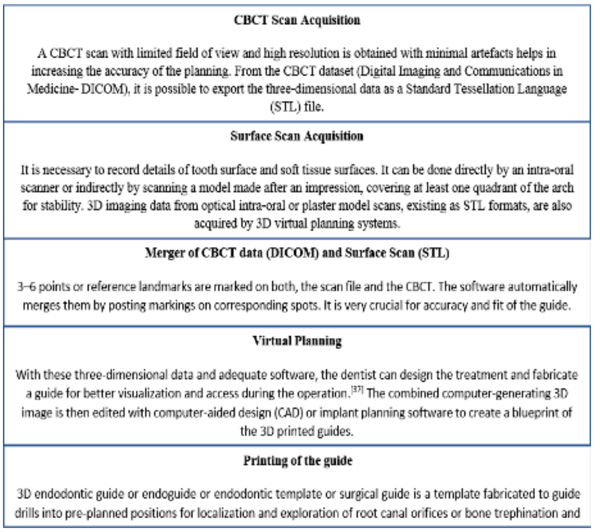
1. A significant problem affecting the image quality and diagnostic accuracy of CBCT images is the scatter and beam hardening caused by high-density neighbouring structures and materials.
2. Crowns, bridges, implants, fillings, and intracanal posts can mimic endodontic complications or hide the existing ones. Fractured files and root canal filling materials also can cause artifacts to develop. [17]
3. Image quality is influenced by several technical factors including device, FOV, voxel size, number of projections, tube voltage, and current. [16]
4. Patient's age has an influence on the image quality of CBCT imaging, and a positive correlation may be found between age and the number of resulting artifacts. The detection of anatomic structures, such as the mental foramen, nasal floor, and mandibular canal, seems to be reduced with increasing age, and this is mainly explained by the fact that older patients may have more dental restorations.[15] These factors may pose a problem and hamper the accurate virtual planning for access opening or periapical surgery.

Software Planning

For successful oral therapy with the use of digital dentistry, it is necessary to have accurate virtual images. Guided endodontics needs a highly accurate guiding sleeve position with an optimum approach angle for minimally invasive access cavity preparation or for microsurgical endodontic access to reduce the risk of damaging critical anatomical structures.

Advances in information technology, including the availability of open-source software allow inter-operability between 3D imaging devices, 3D virtual planning systems and 3D printers to efficiently create, manipulate and process data for the design and production of 3D printed guides.

3D Guide Planning And Designing



CBCT Scan Acquisition

A CBCT scan with limited field of view and high resolution is obtained with minimal artefacts helps in increasing the accuracy of the planning. From the CBCT dataset (Digital Imaging and Communications in Medicine- DICOM), it is possible to export the three-dimensional data as a Standard Tessellation Language (STL) file.

Surface Scan Acquisition

It is necessary to record details of tooth surface and soft tissue surfaces. It can be done directly by an intra-oral scanner or indirectly by scanning a model made after an impression, covering at least one quadrant of the arch for stability. 3D imaging data from optical intra-oral or plaster model scans, existing as STL formats, are also acquired by 3D virtual planning systems.

Merger of CBCT data (DICOM) and Surface Scan (STL)

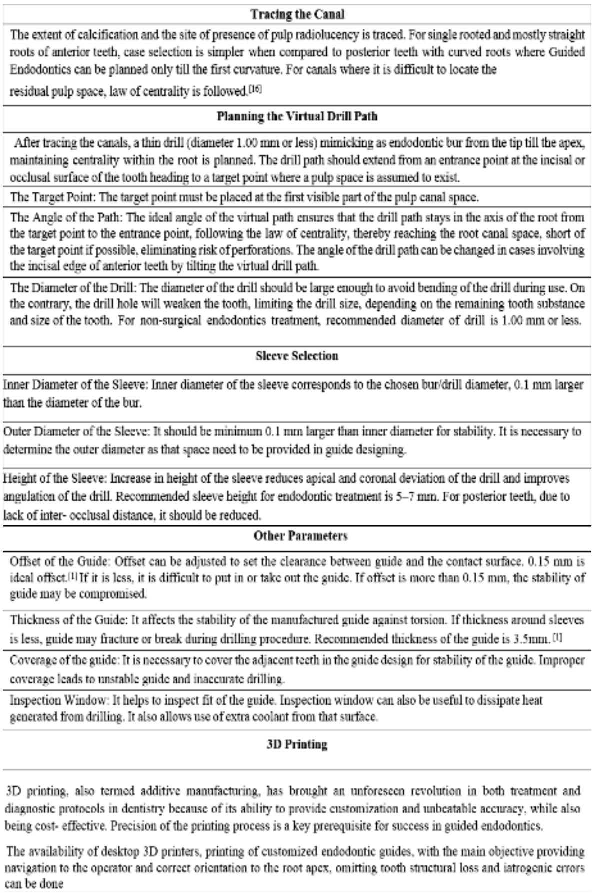
3–6 points or reference landmarks are marked on both, the scan file and the CBCT. The software automatically merges them by posting markings on corresponding spots. It is very crucial for accuracy and fit of the guide.

Virtual Planning

With these three-dimensional data and adequate software, the dentist can design the treatment and fabricate a guide for better visualization and access during the operation.[37] The combined computer-generating 3D image is then edited with computer-aided design (CAD) or implant planning software to create a blueprint of the 3D printed guides.

Printing of the guide

3D endodontic guide or endoguide or endodontic template or surgical guide is a template fabricated to guide drills into pre-planned positions for localization and exploration of root canal orifices or bone trephination and



Tracing the Canal

The extent of calcification and the site of presence of pulp radiolucency is traced. For single rooted and mostly straight roots of anterior teeth, case selection is simpler when compared to posterior teeth with curved roots where Guided Endodontics can be planned only till the first curvature. For canals where it is difficult to locate the residual pulp space, law of centrality is followed.[16]

Planning the Virtual Drill Path

After tracing the canals, a thin drill (diameter 1.00 mm or less) mimicking as endodontic bur from the tip till the apex, maintaining centrality within the root is planned. The drill path should extend from an entrance point at the incisal or occlusal surface of the tooth heading to a target point where a pulp space is assumed to exist.

The Target Point: The target point must be placed at the first visible part of the pulp canal space.

The Angle of the Path: The ideal angle of the virtual path ensures that the drill path stays in the axis of the root from the target point to the entrance point, following the law of centrality, thereby reaching the root canal space, short of the target point if possible, eliminating risk of perforations. The angle of the drill path can be changed in cases involving the incisal edge of anterior teeth by tilting the virtual drill path.

The Diameter of the Drill: The diameter of the drill should be large enough to avoid bending of the drill during use. On the contrary, the drill hole will weaken the tooth, limiting the drill size, depending on the remaining tooth substance and size of the tooth. For non-surgical endodontics treatment, recommended diameter of drill is 1.00 mm or less.

Sleeve Selection

Inner Diameter of the Sleeve: Inner diameter of the sleeve corresponds to the chosen bur/drill diameter, 0.1 mm larger than the diameter of the bur.

Outer Diameter of the Sleeve: It should be minimum 0.1 mm larger than inner diameter for stability. It is necessary to determine the outer diameter as that space need to be provided in guide designing.

Height of the Sleeve: Increase in height of the sleeve reduces apical and coronal deviation of the drill and improves angulation of the drill. Recommended sleeve height for endodontic treatment is 5–7 mm. For posterior teeth, due to lack of inter- occlusal distance, it should be reduced.

Other Parameters

Offset of the Guide: Offset can be adjusted to set the clearance between guide and the contact surface. 0.15 mm is ideal offset.[1] If it is less, it is difficult to put in or take out the guide. If offset is more than 0.15 mm, the stability of guide may be compromised.

Thickness of the Guide: It affects the stability of the manufactured guide against torsion. If thickness around sleeves is less, guide may fracture or break during drilling procedure. Recommended thickness of the guide is 3.5mm. [1]

Coverage of the guide: It is necessary to cover the adjacent teeth in the guide design for stability of the guide. Improper coverage leads to unstable guide and inaccurate drilling.

Inspection Window: It helps to inspect fit of the guide. Inspection window can also be useful to dissipate heat generated from drilling. It also allows use of extra coolant from that surface.

3D Printing

3D printing, also termed additive manufacturing, has brought an unforeseen revolution in both treatment and diagnostic protocols in dentistry because of its ability to provide customization and unbeatable accuracy, while also being cost- effective. Precision of the printing process is a key prerequisite for success in guided endodontics.

The availability of desktop 3D printers, printing of customized endodontic guides, with the main objective providing navigation to the operator and correct orientation to the root apex, omitting tooth structural loss and iatrogenic errors can be done

Classification Of Endodontic Guides

➢ Based On Their Use In Endodontic Treatment:

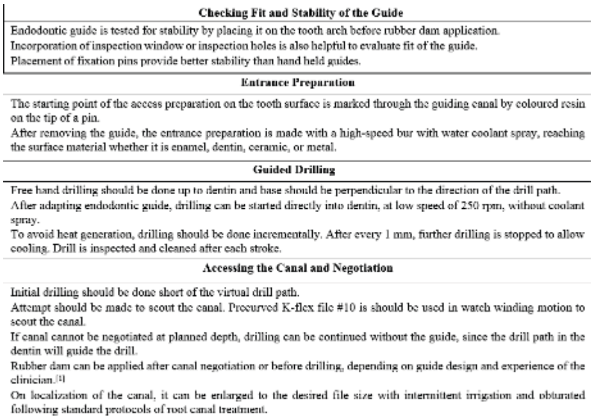
1. Non-surgical Guides: Used for Guided access cavity preparation
2. Surgical Guides: Used for periapical surgery

➢ Based On Their Support:

1. Tooth supported guide: Rests over teeth of the patient with no requirement for anchor pin. Used mainly for non-surgical guided endodontic treatments.
2. Mucosa supported guide: Rests over patient's soft tissues with fixation pins inserted into mucosa. Not preferred for endodontic treatments.
3. Bone supported guide: Rests on bone surface after the flap reflection with fixation pins inserted into bone. It is mostly used for surgical endodontics.

Designing Of Endodontic Guide

Static Guided Access Step-by-step Workflow



Checking Fit and Stability of the Guide
Endodontic guide is tested for stability by placing it on the tooth arch before rubber dam application. Incorporation of inspection window or inspection holes is also helpful to evaluate fit of the guide. Placement of fixation pins provide better stability than hand held guides.
Entrance Preparation
The starting point of the access preparation on the tooth surface is marked through the guiding canal by coloured resin on the tip of a pin. After removing the guide, the entrance preparation is made with a high-speed bur with water coolant spray, reaching the surface material whether it is enamel, dentin, ceramic, or metal.
Guided Drilling
Free hand drilling should be done up to dentin and base should be perpendicular to the direction of the drill path. After adapting endodontic guide, drilling can be started directly into dentin, at low speed of 250 rpm, without coolant spray. To avoid heat generation, drilling should be done incrementally. After every 1 mm, further drilling is stopped to allow cooling. Drill is inspected and cleaned after each stroke.
Accessing the Canal and Negotiation
Initial drilling should be done short of the virtual drill path. Attempt should be made to scout the canal. Procurved K-flex file #10 is should be used in watch winding motion to scout the canal. If canal cannot be negotiated at planned depth, drilling can be continued without the guide, since the drill path in the dentin will guide the drill. Rubber dam can be applied after canal negotiation or before drilling, depending on guide design and experience of the clinician.[1] On localization of the canal, it can be enlarged to the desired file size with intermittent irrigation and obturated following standard protocols of root canal treatment.

Static guided endodontics has been successfully used for anterior teeth. However, with caution, this method can also be applied to premolar and molar teeth if the inter-occlusal distance is optimum to accommodate endodontic guide, bur (drill) and handpiece. The 3D printed guides can be made to fit all diameters, but still the length of the drill sets a limit of the selection. The sizes of the burs used (diameter, 1.2–2.4 mm) are not suitable for the treatment of teeth with PCO and narrow roots such as mandibular incisors. Miniaturized instruments with diameters of only 0.85 mm can be fabricated for the same, giving rise to the concept of microguided endodontics.

For guided treatment of posterior teeth, good armamentarium and adequate inter-occlusal distance are the key to success. To place a guide and endodontic drills in posterior teeth, adequate mouth opening is a necessity. To use more than 10 mm long burs over the guide ring position, inter-occlusal space must be pre-evaluated. Use of short drills and planning angulated access for the drill, depending on canal projection should be done.

Root canal re-treatment is traditionally considered an "all or none" treatment approach. In contrast, surgical endodontics is not viewed as an "all or none" treatment approach. Traditionally, only the diseased root(s) is addressed via root-end resection and root-end filling. Selective root re-treatment combines the approach of non-surgical retreatment with the selectivity of surgical root resection. In this manner, re-treatment could be limited to a single root or roots clearly showing periapical pathosis while leaving the root(s) with no visible or perceived pathosis untouched. Presuming that the existing restoration is of sound marginal integrity and showing no signs of recurrent caries, smaller precision slot accesses can be designed to minimize damage to the restoration and maximize its current structural integrity.

Any drill with diameter ranging from 0.75 to 1.2 mm can be used for drilling. Recommended sleeve height for posterior teeth is 5–6 mm. For multi-rooted teeth, usually one guide is not enough and a virtual drill guide has to be planned for each root canal. For example, for calcified mesiobuccal and palatal canals of maxillary first molar, two different endodontic guides may be needed. Guides are fabricated through rapid prototyping and allow the correct orientation of a cylindrical drill used to provide access through the calcifications.

A modification of guided endodontics was devised with the purpose of reducing the need for interocclusal space using an intracoronal guide technique whereby it can be applied more often in the posterior region for one canal of the multi rooted teeth.[22] Using the guide sleeve as a template, when a pin of diameter 1.2 mm reaches the furcal floor without touching any of the walls, the chamber is filled with composite resin and light-cured to match the correct angulation to access the coronal part of the obliterated canal. This technique is helpful in cases with less interocclusal clearance.

Limitations

1. A static guide for guided endodontics will only work for straight parts of root canals.
2. The tooth must be able to stay in a fixed position during the CBCT scanning and during the guided drilling. (Teeth with poor periodontal health should be contraindicated to avoid errors in planning and drilling.)
3. Presence of metallic restoration or fillings of the teeth may lead to artifacts on a radiograph and may lead to inaccuracies in treatment planning.
4. Limitation of availability of armamentarium (long neck small diameter drills and sleeves).

Surgical Guided Endodontics

Surgical endodontics has gone through spectacular development in the last decades. Earlier research indicated moderate success rates, as low as 30–40%.[25] The first step toward a more successful treatment was the evolution of concept of retrograde filling in the early 1990s. Studies with higher success rates (more than 90%) have consistently used high-power magnification, dental operating microscope.[26] Success rate of surgery can increase from approximately 60–70% to 90–94%, when the cut is performed at 90° instead of 45°.[27] It has been suggested that the removal of a 3 mm of root end ensures the elimination of the ramifications and lateral canals in over 90% of the cases.[28]

Limitations Of Conventional Endodontic Surgery

1. Site and size of osteotomy with precise angulation are difficult to reach, if no aids are used. Precise root-end resection of apical 3 mm of the apex is not easy either.
2. Furthermore, the diameter of the osteotomy should optimally be kept as small as 3–4 mm to avoid excessive postoperative pain and prolonged healing.[29]

A study by Pinsky et al. was the first to demonstrate that the guided approach does improve accuracy.[9] This has been recently affirmed by Hawkins et al., who have proven in a surgical simulation scenario, that targeted endodontic microsurgery provided more efficient completion of osteotomy and resection, with a more appropriate root-end resection volume and bevel angle than conventional endodontic microsurgery.[30]

The first truly guided case of endodontic surgery was reported by Giacomino et al. in 2018.[31] The authors used a 3D printed guide for combined osteotomy and root-end resection with a round bone trephine. They concluded that the guide was useful for the control of the depth and angulation of the osteotomy. In another case report, Strbac and colleagues used a stereolithographically fabricated surgical template for osteotomy and root resection.[32] This template helped the operator to locate the root apices during surgery, though it did not guide the drill itself.

Types Of Surgical Guides

1. Non guiding 3D Printed Template to Help Access

These templates are designed to define the surgical area. They retract soft tissues to ensure access to the surgical site. Such surgical aids do not localize the root apex, neither do they guide a drill nor bone trephine. These aids are used as localizing tissue retractors.

2. 3D Printed Template for Cortical Preparation

This guide helps to define the exact site where the cortical bone should be penetrated for root-end resection. After placing the template, a short drill ocortical trephine is applied through it to mark the cortical bone.[33] This template helps to define osteotomy site over the root apex, but they do not help the operator to find the right angulation or length of root end resection. With this method, only initial guidance is achieved. This approach cannot guarantee that the drilling will actually reach the apex, even if it is started in the right direction.

3. Pilot Guide

A guiding template is used for drilling with a small diameter drill (the "pilot" drill). Initial drilling is performed with this drill through the template and the resulting bony cavity provides guidance to subsequent drills applied without the template. With this method, clinicians can reach safely within 1 mm of the root apex.

4. Full Guide for a Bone Trephine

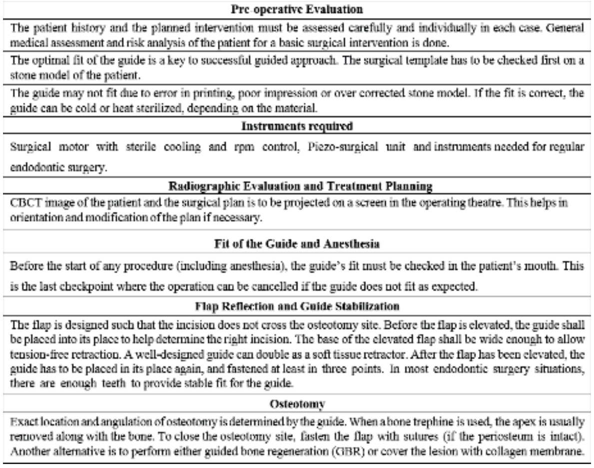
To ensure precise osteotomy and apex removal, fully guided endodontic surgery should be planned. It is important that the diameter of the drilling sleeve should correspond to the external diameter of the trephine to be used to ensure stability. The trephine is a hollow trephine in a surgical contra-angle handpiece. Sterile irrigation must always be used, and rotational speed must be kept low, not exceeding 800 RPM.

5. Bone Trephine with a Stop

To prevent overpenetration of the drill, a bone trephine with a stop should be used. Such a trephine shall meet two critical criteria. First, the body and the cutting part shall have the same diameter in order to pass through the guide without friction, and second, they shall have a stop at the base.

The first set of recommendations for a surgical endodontic workflow was given by Liu et al. in 2014.[34] In the recent years, the field has seen many developments that justify revision.

Step By Step Workflow



Pre operative Evaluation
The patient history and the planned intervention must be assessed carefully and individually in each case. General medical assessment and risk analysis of the patient for a basic surgical intervention is done.
The optimal fit of the guide is a key to successful guided approach. The surgical template has to be checked first on a stone model of the patient.
The guide may not fit due to error in printing, poor impression or over corrected stone model. If the fit is correct, the guide can be cold or heat sterilized, depending on the material.
Instruments required
Surgical motor with sterile cooling and rpm control, Piezo-surgical unit and instruments needed for regular endodontic surgery.
Radiographic Evaluation and Treatment Planning
CBCT image of the patient and the surgical plan is to be projected on a screen in the operating theatre. This helps in orientation and modification of the plan if necessary.
Fit of the Guide and Anesthesia
Before the start of any procedure (including anesthesia), the guide's fit must be checked in the patient's mouth. This is the last checkpoint where the operation can be cancelled if the guide does not fit as expected.
Flap Reflection and Guide Stabilization
The flap is designed such that the incision does not cross the osteotomy site. Before the flap is elevated, the guide shall be placed into its place to help determine the right incision. The base of the elevated flap shall be wide enough to allow tension-free retraction. A well-designed guide can double as a soft tissue retractor. After the flap has been elevated, the guide has to be placed in its place again, and fastened at least in three points. In most endodontic surgery situations, there are enough teeth to provide stable fit for the guide.
Osteotomy
Exact location and angulation of osteotomy is determined by the guide. When a bone trephine is used, the apex is usually removed along with the bone. To close the osteotomy site, fasten the flap with sutures (if the periosteum is intact). Another alternative is to perform either guided bone regeneration (GBR) or cover the lesion with collagen membrane.

Anterior teeth are mostly easy to access even at the level of the apex, but in some cases, the vestibular area can be really tight or the lips of the patient do not allow retraction for 90° penetration at the root end.

Premolars are a bit more difficult to access, but if the mobility of the vestibule is sufficient, guided surgery can be performed. The guided approach is especially advantageous in the lower premolar area, where the protection of the mental nerve is a concern. Minor spatial limitations can be overcome by slightly oblique planning toward the mesial so that the trephine will penetrate the bone not exactly at 90°, that is, the penetration can be perpendicular to the root, even if it is not perpendicular to the surface of the bone. Compared to conventional osteotomy, this approach will still preserve much more bone.

Molar teeth are always challenging. If the guided approach is chosen, molar roots are accessible almost only with a mesially oblique penetration from the buccal side.

Most bone trephines have length of 10–20 mm. if a short trephine is planned, the thickness of the soft tissue must always be assessed. In contrast, planning with a long trephine carries the risk of overpenetration and suboptimal guidance. A bone trephine for guided endodontic surgery is of the same diameter along its entire length.

Limitations

1. In contrast to guides, used in orthograde endodontics or implantology, in surgical endodontics, the access needs to be in the apical area, which should be perpendicular to the root axis. To reach this end, the apical area needs to be registered as accurately as possible, either with an oral scanner or with regular dental impression.
2. Distal locations, long roots, narrow vestibule, or even limited mouth opening can cause difficulties in accurate registration and subsequent access of apical area.

Dynamic Navigation

Dynamic navigation is a promising technology designed to guide the placement of drills/implants in real time by a computer. It is based on information generated from the patient's computed tomography (CT).

Principles Of Dynamic Navigation

Modern dynamic surgical navigation systems use a stereoscopic camera, with or without, emitting infrared light, which can determine a 3D position of prominent structures, like reflective marker spheres This allows for real-time tracking of the marker spheres.

For dynamic navigation, the requirements are a stereoscopic camera, a computer platform with screen, and the respective navigation software. During the surgery, the marker spheres are attached to the patient and at surgical instruments (using reference arrays) to enable an exact localization in space and, hence, navigation in the operating room (OR).

With each reference array comprising of at least three marker spheres, the computer can calculate the position and orientation of each instrument. A correct localization and virtual display of the instrument on the computer screen is ensured by firmly attaching a reference array to the patient, either in the bone or via a head clamp. Movements of the camera intraoperatively are possible, because only the relative position of the tracked instruments to the tracked patient reference is relevant.

The navigation software calculates an individual model of the patients' anatomy based on defined landmarks on the bone, which are acquired using a navigated instrument (registration). Dynamic navigation system is empowered by a motion tracking technology, which tracks the dental drill and patient position throughout the procedures by integrating surgical instruments, three-dimensional images, and optical positioning devices. In this improved setup, an optical-motion-tracking system provides feedback during surgery, and therefore, the designed information is linked to the real-time clinical situation and the equipment used for the intervention. It facilitates the traceability of instrument position. This method provides flexibility for the person performing the surgery, as in case of unexpected need of modifications, these can be done any time during the intervention.

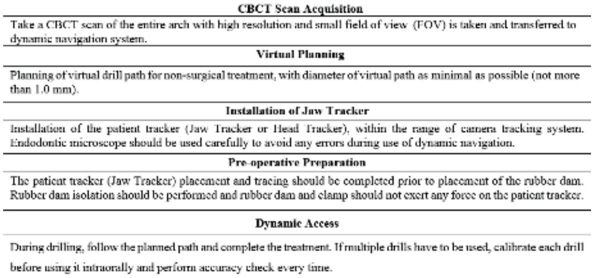
The current dynamic navigation systems display the images on the monitor using optical technologies to track the patient and the handpiece. The optical systems use either active or passive tracking arrays. Active system arrays emit light, which is tracked by the stereocameras. Passive systems use tracking systems in which the light emitted from a light source is reflected back to the stereocameras.

Dynamic Navigation Components

The basic components of any dynamic navigation systems are as follows:

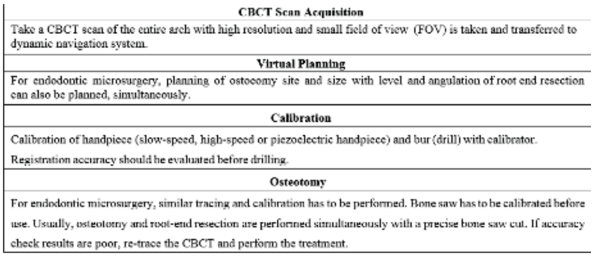
- Handpiece attachment
- Patient jaw attachment
- The system cart, which consists of the cameras, a computer with a navigation software
- Natural or fiducial markers that are used during the radiological scan as reference points for the instrument registration (Optional)

Step-by-step Workflow For Non- Surgical Endodontics



CBCT Scan Acquisition
Take a CBCT scan of the entire arch with high resolution and small field of view (FOV) is taken and transferred to dynamic navigation system.
Virtual Planning
Planning of virtual drill path for non-surgical treatment, with diameter of virtual path as minimal as possible (not more than 1.0 mm).
Installation of Jaw Tracker
Installation of the patient tracker (Jaw Tracker or Head Tracker), within the range of camera tracking system. Endodontic microscope should be used carefully to avoid any errors during use of dynamic navigation.
Pre-operative Preparation
The patient tracker (Jaw Tracker) placement and tracing should be completed prior to placement of the rubber dam. Rubber dam isolation should be performed and rubber dam and clamp should not exert any force on the patient tracker.
Dynamic Access
During drilling, follow the planned path and complete the treatment. If multiple drills have to be used, calibrate each drill before using it intraorally and perform accuracy check every time.

Step-by-step Workflow For Surgical Endodontics (figure 6)



CBCT Scan Acquisition
Take a CBCT scan of the entire arch with high resolution and small field of view (FOV) is taken and transferred to dynamic navigation system.
Virtual Planning
For endodontic microsurgery, planning of ostoeomy site and size with level and angulation of root end resection can also be planned, simultaneously.
Calibration
Calibration of handpiece (slow-speed, high-speed or piezoelectric handpiece) and bur (drill) with calibrator. Registration accuracy should be evaluated before drilling.
Osteotomy
For endodontic microsurgery, similar tracing and calibration has to be performed. Bone saw has to be calibrated before use. Usually, osteotomy and root-end resection are performed simultaneously with a precise bone saw cut. If accuracy check results are poor, re-trace the CBCT and perform the treatment.

Advantages Of Dynamic Navigation System

1. CT scanning, planning, and surgery in a single appointment (when a CBCT is available on site).
2. Reduced harm to the patient: minimally invasive surgery, leading to reduced patient discomfort, reduced risk of infection, and faster recovery. Another benefit of microsurgery is the minimization and eventual elimination of inclination of root end resection.
3. Unintentional iatrogenic damage to nearby anatomical structures.
4. Increased safety and predictability due to ability to verify guidance accuracy at any time. Several sources of error such as radical osteotomy, inaccuracy of localization, and injury of critical anatomical structures are eliminated.
5. Simpler and faster planning (no plaster models, wax-ups, and guide fabrication).
6. Ability to view and modify the plan during the surgery, for example, to accommodate tactile feedback or unexpected complications. The operator can accurately check and correct any errors on the spot, since the instruments are calibrated and strictly observed during surgery.
7. Cost-effective. (Lower per-procedure costs).
8. Improved irrigation, reducing risk of bone damage due to overheating.
9. No need of specialized equipment. Works with any implant or drill system.
10. Without sleeves, guidance is provided even when interocclusal or interdental space is limited.
11. Elimination of guidance failures due to fractured or badly fitting guides.
12. Improved ergonomics.[35]

Limitations Of Dynamic Navigation System

1. One of the main difficulties with the dynamic navigation system is the high cost of the navigation system, its updates, and maintenance of the system, which might not be financially feasible for the surgeon.
2. Every system has its own planning software; thus, one might not be able to use any other advanced software.
3. Adequate learning is expected from the clinician as a learning curve is associated with it.

CONCLUSION

The concept of guided access is of great value in cases with unusual anatomies, pulp canal obliterations and root canal re-treatment for localization of the root canal space and at the same time, avoiding substantial loss of tooth structure and iatrogenic errors such as perforation, root canal transportation and instrument separation. It improves precision by virtual planning of the operative procedure beforehand using the CBCT scan and Surface scan of the patient.

Guided microsurgery is helpful in difficult to approach apical anatomies rather hindered by the proximity to vital structures. It offers minimally invasive surgical access to the apical area and prevents damage to the adjacent vital structures.

Dynamic navigation eliminates the clinical errors as well as the errors which can occur in the planning phase of the guided access. It offers a valuable alternative for endodontic surgery with visualization of the position of the instrumentation.

Guided endodontics has limitations in terms of availability of adequate facilities and addition cost in daily practice, but it is of great value in cases where the conventional approach to endodontics is difficult and chances of damage to vital structures and tooth substance loss has to be prevented.

Current literature on guided endodontics constitutes majorly of case reports of individual operations. In vitro studies for comparison of conventional and guided approaches have been done, but clinical trials need to be conducted with long term follow up.

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