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Guided Endodontics

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Abstract: The conceptual framework of guided endodontics is used to prepare access cavities and perform endodontic operations in a predictable and secure manner. There is less potential for iatrogenic harm, and the outcomes are highly predictable. This strategy can benefit endodontic or surgical treatment of challenging cases. Although it can be employed for many different procedures, it is especially useful for microsurgical endodontics, glass fibre post removal during endodontic retreatments, and accessing and detecting root canals in teeth with pulp canal obliteration. Furthermore, compared to traditional endodontics, it is safer, more accurate, and takes less time for the patient to obtain treatment. It is also independent of a clinician's level of competency.The primary goal of this paper is to produce an updated literature review on guided endodontics based on the scientific material that has been published thus far.

Index Terms - Guided endodontics, Pulp Canal Obliteration, Guided approach, 3D Printing, CBCT Scan.

I. INTRODUCTION

Breathtaking technological advancements over the last few decades have significantly impacted our lives. From computers to smartphones, single purpose to multipurpose devices, technology has become an intrinsic part of our daily routine. There are numerous examples of technological advances in the fields of both medicine and dentistry, where the benefits to patients have been clearly evident and hence rapidly adopted and integrated into our daily clinical routine.

These advancements have revolutionized the medical field, transforming the way healthcare is delivered, diagnoses are made, and treatments are administered. From cutting-edge imaging techniques to innovative surgical tools, these advancements have significantly improved patient outcomes, enhanced efficiency, and expanded the scope of medical research. This introduction sets the stage for exploring the myriad ways in which technology has reshaped healthcare, paving the way for a healthier and more connected world.

Navigation in dentistry is an important example of technological advancements applied to medicine and health science. 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 surgical interventions into safer, predictable, and less invasive procedures.

II. EVOLUTION OF DIGITAL DENTISTRY

The digital revolution is changing the world, and dentistry is no exception. The introduction of digital devices and processing software together with new aesthetic materials and powerful manufacturing tools are radically transforming the dental profession. Quest for safer, less invasive, and predictable treatments has transformed dentistry as well. Today, the digital revolution is changing the workflow and consequently changing operating procedures. In modern digital dentistry, the four basic phases of work are image acquisition, data preparation/processing, the production, and the clinical application on patients. Classically, case history and physical examination, along with X-ray data from two-dimensional radiology (periapical, panoramic, and cephalometric radiographs), represented the necessary preparatory stages for formulating a treatment plan and for carrying out the therapy. With only two-dimensional X-ray data available, making a correct diagnosis and an appropriate treatment plan could be difficult; therapies essentially depended on the manual skills and experience of the operator. 3D guided endodontics helps not only in diagnosis and treatment planning but can also be used as an efficient tool in executing the treatment. Digital dentistry involves use of digital devices, processing software, and manufacturing tools. Data or image acquisition is the first operational phase of digital dentistry.

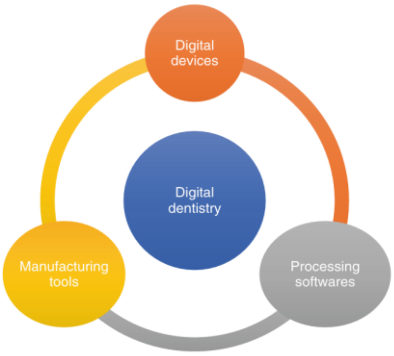


Fig. Triad of digital dentistry

It employs digital devices such as digital cameras, intraoral scanners, extraoral scanners, face scanners, CBCT, and micro-CT with low radiation dose. Digital photography, combined with the use of appropriate software for image processing, allows us to design a patient's smile virtually. It is called digital smile design, a valuable tool for previsualization and communication in modern aesthetic and cosmetic dentistry. Intraoral scanners allow us to take accurate optical impression of the dental arches, using only a beam of light. The optical impression is now replacing the classic method with tray and impression materials. The information on dentogingival tissues acquired from an optical impression can be used not only to make a diagnosis and for communication, but also to design prosthetic restorations. Indeed, optical impression data (e.g., the scanning of prosthetic preparations) is easily imported into processing software for designing/planning prosthetic restorations; the models created in this way are then physically produced with materials of high esthetic value, with powerful milling machines.

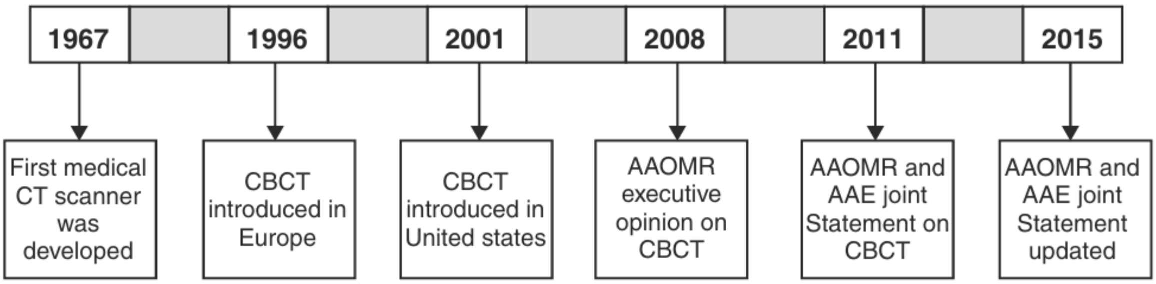
Access cavity preparation is considered a fundamental step in orthograde endodontic treatment. The first step to gain access to root canal treatment is to prepare a coronal cavity, which is crucial for the results, stability, and longevity of the tooth.[1] An access cavity that has been prepared improperly in terms of position, depth, or extent hinders the achievement of optimal results.[2] Straight-line access to the orifices of the root canals is recommended[3] but, recently, minimal invasive concepts are also preconized[4]. Contracted endodontic cavities (CECs) have stemmed from the concept of minimally invasive dentistry. Guided Endodontics is also known as Targeted Endodontic Treatment (TET).

Guided endodontics can deliver more predictable treatment outcomes compared to conventional treatment strategies. Guided approach can be static or dynamic. "Static guided Endodontics" is a way to use CBCT merged with an optical impression, creating the platform for the design of a virtual drill path subsequent to the clinical procedure of drilling using a guide. Pulp canal obliteration or calcification is characterized by the deposition of hard tissue within the root canal space.

When a young person with a vital tooth and an open apex is exposed to a trauma, the pulp response may result in a narrowing of the pulp cavity by deposition of hard tissue. In anterior teeth, it occurs commonly as a result of concussion, subluxation, or luxation injuries[5]. In elderly patients, the ongoing deposition of both secondary and potential tertiary dentin may reduce the root canal space as well. External injuries resulting in tertiary dentin can be caused by caries, wear, irritation from preparations, and/or subsequent filling materials[6]. In these cases, even the most experienced clinicians can encounter difficulties to prepare an adequate access cavity. Guided endodontics is extremely helpful for predictable, minimally invasive, and successful endodontic treatment of such cases. A CBCT scan is an excellent measure for localizing the root canals in order to make an orthograde root canal treatment of seemingly obliterated root canals. In particular, the axial view gives the placement of a canal in relation other landmarks of the tooth: the circumference and the position of the potential other neighboring root canals. These relations can be measured at the CBCT scan, but may be difficult to apply directly with accuracy into the clinical scenario. In contrast, a virtual drill path can be made at the scan with the use of appropriate software. If this virtual drill path shall be converted into a real drill path, some kind of surface guiding based on the CBCT scan is necessary. It could be a dynamic guiding or a static guiding. A static guiding is made by using a guide made from a combination of a CBCT scan and a surface scan, whereas the dynamic guiding uses the CBCT data in combination with recordings of the drill movements running real time. Navigation can support several aspects of endodontic treatment, from localization of calcified canals to guiding the osteotomy for apicoectomy.

III. CBCT IN ENDODONTICS

Medical computed tomography (CT) was first developed by Sir Godfrey Hounsfield in 1967, and since then, many advancements have been made involving detectors, beam source, and movement patterns of the detectors and beam sources[7]. Cone beam computed tomography (CBCT) was first introduced in Europe in 1996 and in the United States in 2001. By 1998, Mozzo et al. had laid the foundation for the new revolution in three-dimensional (3D) imaging by describing how a volumetric CT machine would be useful for dental imaging. For decades, clinicians have relied on standard two-dimensional (2D) images that offered little useful information about the third dimension, z-axis, which denotes depth of the anatomical volume. In last decade, CBCT has become an integral part of dental practices[8].



CBCT is accomplished by using a rotating gantry to which an X-ray source and detector are fixed. A divergent pyramidal- or cone-shaped source of ionizing radiation is directed through the middle of the head and neck, with X-ray detector on the opposite side of the patient. The X-ray source and detector rotate around a fixed fulcrum within the region of interest (ROI). During the exposure sequence, hundreds of planar projection 2D images are acquired of the field of view (FOV) in an arc of at least 180°. The images are then reconstructed to visualize 3D data set, using a variation of the algorithm developed by Feldkamp et al. in 1994[9]. This technique allows clinicians to obtain 2D reconstructed images in all planes, and reconstructions in 3 dimensions with low level exposure to X-radiation[10].

Patient Positioning

Depending on the system employed, maxillofacial CBCT can be performed with the patient in three possible positions:

(1) sitting,
(2) standing, and
(3) supine.

Field of View (FOV)

The size of the FOV describes the scan volume of a particular CBCT machine and depends on the detector's size and shape, the beam projection geometry, and the ability to collimate the beam, which differs from one manufacturer to another. Beam collimation limits the patients' ionizing radiation exposure to the ROI and ensures that an appropriate FOV can be selected based on the specific case.

CBCT units can be classified into small, medium, and large volume based on the size of their FOV. [Fig. 1][11]

In endodontics, the area of interest is limited, and small-volume CBCT machines are preferred, because there is less radiation dose to the patient, higher spatial resolution, and shorter volumes to be interpreted.

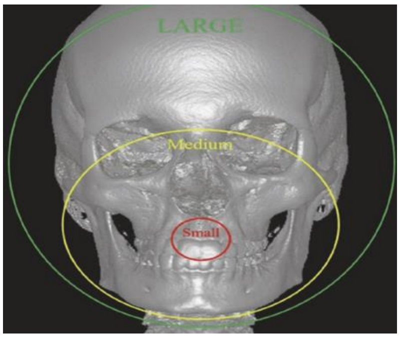


Fig.1 Area covered by small, medium, and large FOVs.

Cone Beam Computed Tomography Image Formation

The image formation process consists of three stages:

1. Acquisition stage
2. Reconstruction stage
3. Image display

IV. DIGITAL IMPRESSIONS IN CAD/CAM

For successful oral therapy with the use of digital dentistry, it is necessary to have accurate virtual images[12]. Failures can arise if the scanned images are not accurate enough. Sufficient accuracy, in this context, means clinically acceptable accuracy. This, of course, can be different in each segment of dentistry. Facial tissue scanning accuracy ranges between 140 and 1330 µm, which is acceptable for a smile design project. When reconstructing the dataset of a cone-beam computer tomography (CBCT) scan, jawbone scanning accuracy will be around 100–700 µm. This deviation range is a bit wider than that achievable by CT, which can be as low as 100 µm but comes at a much higher radiation dose cost to the patient. Navigated implant placement seems to work appropriately within CBCT's deviation range. Intraoral optical impression accuracy ranges between 16 and 378 µm, but its trueness and precision highly depend on scanning strategy, scanning technology, scanned area size, and actual clinical situation[12]. Extraoral laboratory scanners work within a range of 20–55 µm; their accuracy depends not as much on the specific technology (whether it is a laser or a structured light scanner) as on certain dental parameters such as the shape and margin ends of the scanned abutment[13]. The clinically acceptable range for the marginal discrepancy of a crown ranges extensively between 30 and 140 µm based on different reports. The clinically acceptable level in most studies is ≤120 µm[14]. In digital dental treatment, accurate and precise work should aim to be close to 50 µm, which can be easily achieved with modern equipment.

Guided endodontics needs a highly accurate guiding sleeve position with an optimum approach angle for minimally invasive access cavity preparation or for micro surgical endodontic access to reduce the risk of damaging critical anatomical structures[15]. A preoperative CBCT might be necessary in exceptional cases such as complicated endodontic anatomy, root resorption, or pulp canal calcification, even if this means a higher radiation dose for the patient. From the CBCT dataset (DICOM), it is possible to export the three-dimensional data as an STL file. These data can be combined with an STL generated using an intraoral digital impression system. 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[16].

4.1Direct and Indirect CAD/CAM Approaches

Dental CAD/CAM systems consist of various hardware and software used for data acquisition as well as restoration design and manufacture. They serve three main functions: (1) three-dimensional digitization and generation of a digital data set; (2) a design manipulation process for generating the manufacturing data set; and (3) fabrication of dental restoration by a digitally controlled system.[Fig.2]

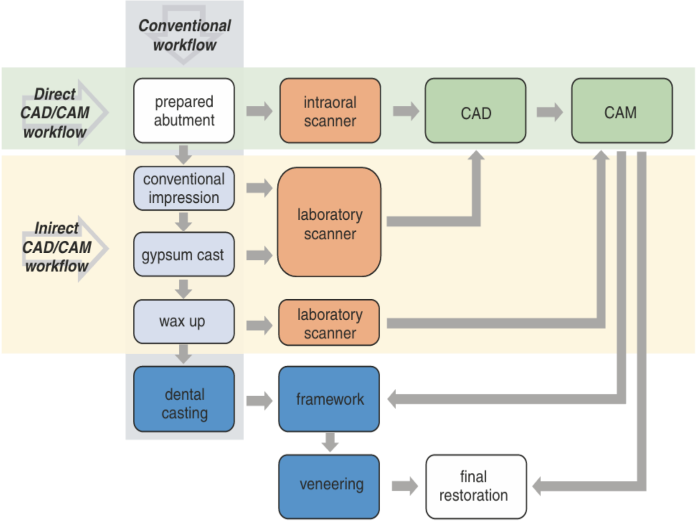


Fig. 2 Flowchart of the direct and indirect CAD/CAM workflow compared to the conventional workflow of processing a restoration. Orange shows the digitizing procedures.

4.2 STL File Extension

The STL file is a data file format for computers containing information of an object's geometry by describing it with connected triangles. The triangles' density depends on the initial resolution and mathematical algorithms. The STL extension is a hard-disk data file for a computer. The acronym's origins are explained in several ways: standard tessellation language, standard triangle language, and stereolithography are all terms in use.

4.3 Digital Workflow with Indirect CAD/CAM Impression Systems

Indirect CAD/CAM methods are based on scanning the stone model made from conventional impressions with an extraoral (laboratory) scanner. The digital workflow starts with a PVS (polyvinylsiloxane) impression of prepared teeth; a sectioned gypsum model is then made, and a laboratory scanner creates a 3-dimensional set of points on the spatial information of the dies and the whole arch. Thus, the resulting virtual cast is a realistic digital model of patient's oral cavity. Design is done on computer screen using CAD software. Dental technicians can design frameworks/ substructures or full-contour restorations. Finally, the virtual wax-up is processed by a milling machine. Following the milling process, substructures need to be veneered, and full-contour restorations stained and glazed. There are also systems where a complete conventional wax-up is made and then digitized to create a digital- wax pattern followed by automatic processing.

4.4 Digital Workflow with Direct CAD/CAM Impression Systems

Direct impression means taking an intraoral digital impression directly of the prepared and unprepared teeth by an intraoral scanner. Intraoral scanners create a digital replica of the patient's dentition on computer screen. The scan can be analyzed when magnified and additional scans may be added for perfection. After verification, the digital file is imported into a CAD software program to virtually design either a coping, a substructure, or full-contour restoration. Restorations are milled, and in case of a coping or substructure, a model may be printed to apply veneering ceramics.[Fig. 3]

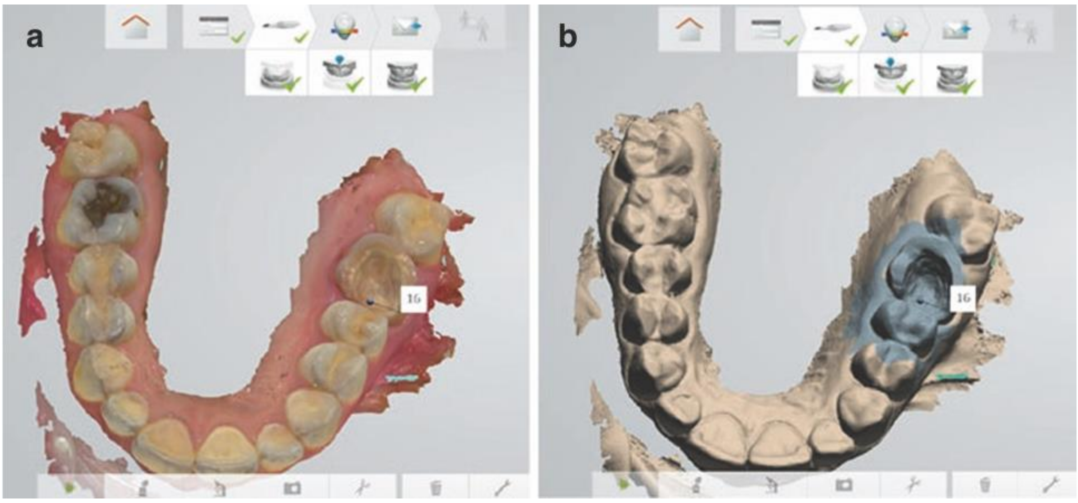


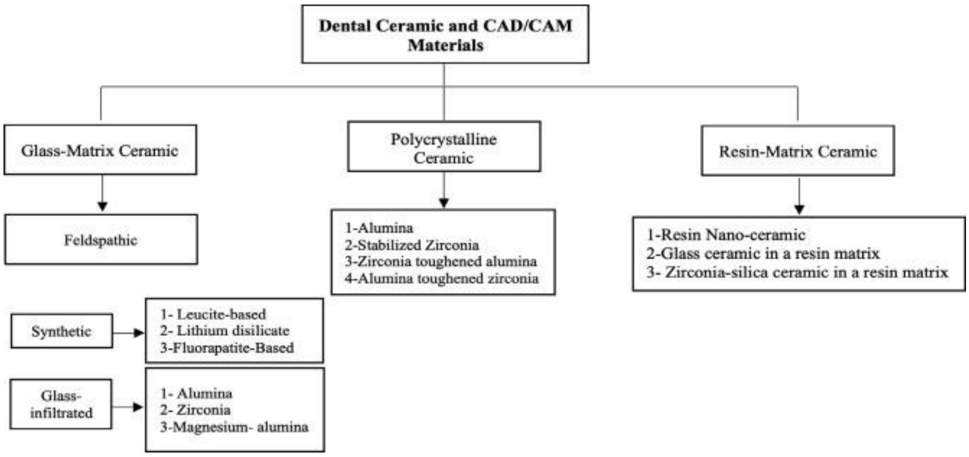
Fig. 3 (a) Intraoral scan of a patient's upper arch with the prepared onlay cavity, (b) the digital replica of the patient's dentition rendered on a computer screen.

4.5 Computer-Aided Manufacturing (CAM)

Restorations designed by CAD software are fabricated by direct digital manufacturing devices. These devices can be divided into two main categories: subtractive and additive manufacturing technologies[17]. Subtractive manufacturing is the more common technology. This technique utilizes burs to mill the restoration (frame works, copings, full-contour restorations) from a block of material. Cutting paths are generated by computer[18]. Production is based on conventional computer numerical control (CNC) milling. Subtractive technologies are generally limited by geometric complexity and are not suitable for producing all shapes; additive manufacturing can fabricate far more complex organic forms[19]. Additive manufacturing technologies originate from the area of Rapid Prototyping (RP) adapted to the needs of dental technology. They generally slice the 3D model into regular planes with instructions for material deposition, polymerization, or fusing in each plane. New additive technologies include: stereolithography, selective laser sintering (SLS), 3-D printing, fused deposition modeling (FDM), solid ground curing, and laminated object manufacturing (LOM)[18].

4.6 Materials for CAD/CAM

Advances in CAD/CAM technology software and hardware have facilitated the development of new improved ceramic materials. Early generations of materials were monochromatic, but that was not the main problem associated with CAD/ CAM restorations. Restorations had poor marginal fit, anatomy and morphology, and a general lack of internal adaptation to the die because of low resolution scans, inadequate design software, and machining shortcomings. Technological advances in new systems and software development, coupled with specific clinical and laboratory techniques, have minimized or eliminated these problems so that marginal integrity and internal adaptation can be excellent[20].



V. 3D GUIDE

3D endodontic guide or endo guide is a template fabricated to guide drills into pre- planned positions for localization and exploration of root canal orifices or bone trephination and root end re-section. It is a method of static navigation in endodontics.

Synonyms
- Endodontic guide
- Endo guide
- Endodontic template
- 3D Endodontic guide/template
- Surgical guide

5.1 Types of Endodontic Guides

Endodontic Guides and Software Planning
1. Depending upon their use in endodontic treatment:
(a) Non-surgical Guides (b) Surgical Guides
2. Depending upon their support:
(a) Tooth supported guide (b) Mucosa supported guide (c) Bone supported guide
3. Classification of Surgical endodontic templates:
(a) Non-guiding template for soft tissue retraction
(b) Template for cortical preparation
(c) Template for pilot guide
(d) Full guide for a bone trephination and root end resection

5.2 Steps of 3D Guide Planning and Designing

For accurate endodontic guide panning, parameters should be set for virtual panning, drills, sleeves and 3D printing. The basic steps for guided endodontics are as follows:
- CBCT Scan of the Involved Tooth
- The Surface Scan
- Merging the CBCT Scan and Surface Scan with a Software

5.3 Designing of Endodontic Guide

5.3.1 Tracing the Canal

First is to locate the calcified canals on a scan. Mostly, we always can see the trace of pulp radiolucency present which helps to guide you in tracing the entire canals. It is always easy to trace and select case for guided endodontics for anterior teeth where most of the time, there is no curvature. For the canals with curvature, guided access can be provided till first curvature only. If canal is not visible even on CBCT scan, law of canal centrality should be followed while planning.

5.3.2 Creating Virtual Drill Path

On the CBCT scan, a virtual drill path can be planned with the help of appropriate software. As m any software are not customized for endodontic treatment planning, implant software and virtual drills can be used. After tracing the canals, go to software implant or drill library depending upon the software and its manufacturer's instructions. Place a thin implant or drill (diameter 1.00 mm or less) mimicking as endodontic bur from the tip till the apex. Align the drill path along the path of the canal and maintain centrality within the root. Following points should be considered while planning virtual drill path for endodontic guide. 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.

5.3.3 Sleeve Selection

When the target, the angle and the diameter of the bur are decided, a virtual sleeve is added to the scan.

Sleeve Inert Type

There are two type of sleeve inserts: [Fig. 4]
1. Hand-hold sleeve inserts (drill key)
2. Drill-hold sleeve inserts (guide sleeve)

Hand-hold sleeve does not provide good stability and that can lead to inaccurate drilling. Guide sleeves are recommended for endodontic treatments.

Fig. 4 Drill Key and Guide Sleeve

VI. 3D PRINTING

To establish an additively manufactured driven workflow, one needs access to the three basic technologies constituting the digital inventory, but without any geographical limitations:

1. 3D image acquisition with intraoral scan, computed tomography (CT) or cone beam CT (CBCT), or optical scanners such as intraoral impression scanners [22]
2. A digital software for conversion of the output files the digital imaging and communications in medicine (DICOM) data of the scanners into a printable format such as the standard tessellation language (STL) files [23]
3. 3D printing system.

The image acquisition reverberates with 3D printing technology as the output is dependent on the quality of volumetric data obtained in the first place[21]. The data source plays a crucial role from image acquisition, rendering and segmentation, designing and reconstruction, to the final printing process[24]. By adjusting imaging parameters, one can optimize the desired quality of the DICOM data for the printing process[25].

3D printers, which are now widely available, work using five basic mechanisms: [Fig. 5]

1. Fused deposition modeling (FDM)
2. Selective laser sintering (SLS)
3. Stereolithography (SLA)/direct light processing (DLP)
4. Poly-jet printing
5. Bioprinting

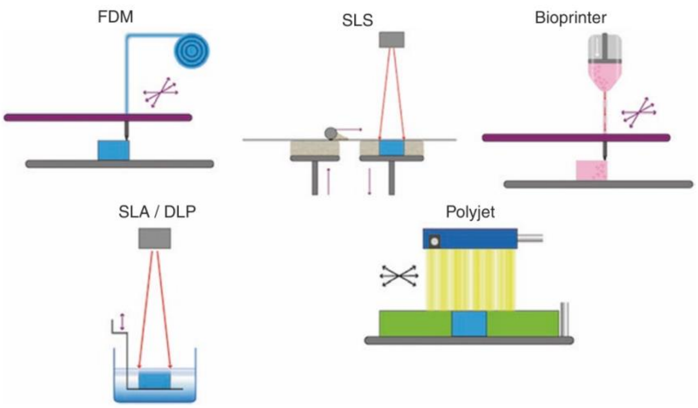


Fig. 5 3D printing systems. 3D printing methods applied in many fields of medicine and dentistry including fused deposition modeling (FDM), selective laser sintering (SLS), stereolithography (SLA), poly-jet, and

VII. STATIC GUIDED ENDODONTICS

7.1 Static Guided Nonsurgical Approach for Calcified Canals of Anterior Teeth

Pulp canal obliteration (PCO) or calcified canals may present distinct diagnostic and treatment challenges. In the presence of calcification, adequate access cavity preparation and identification of root canal orifice are extremely difficult. The American Association of Endodontists (AAE) Case Assessment places these cases into the high difficulty category[26]. Calcified canals pose risk of overextended access cavity preparation, incorrect alignment of the access cavity with the risk of root perforation as well as fracture of root canal instruments during canal preparation[27]. Therefore, precise and predictable preoperative planning is highly recommended, and 3D imaging may be a useful tool. Cone-beam computed tomography (CBCT) helps the clinician to establish a proper strategy to deal with PCO with potential benefits. CBCT is a noninvasive imaging and measuring tool that can represent the tooth in all spatial planes to explore root canal anatomy[28]. Static guided endodontics can be very useful in negotiation and preparation of partly or entirely obliterated pulp chambers and canals[29].

7.2 Root Canal Obliteration and Clinical Challenges

Pulp canal obliteration (PCO) is characterized by the deposition of hard tissue within the root canal space[30]. It is associated with injury to the pulp and, generally, PCO has no symptoms and may be noted via tooth discoloration or routine clinical examination[31]. Moreover, its diagnosis can be more challenging as the response of the tooth to thermal and electric pulp tests can be diminished or even absent[32]. Obliteration of the pulp space may occur as a result of the formation of tertiary dentine, due to chronic caries progression[33], or following tooth restoration[34], and after vital pulp therapy procedures[35]. Also, pulp space obliteration occurs in teeth with open apices following luxation injuries, particularly following lateral luxation, intrusion, and avulsion[36]. Pulp canal calcification may also arise as an adverse effect of excessive orthodontic forces, which interferes with pulpal blood supply[37].

7.3 Considerations for Guided Approach for Posterior Teeth

Indications

- Calcified canals
- Minimal invasive endodontic approach.
- Selective root re-treatments:

7.4 Step-by-Step Clinical Procedure

1. Check stability of the guide on the cast and intra-orally.
2. Evaluate the dimensional accuracy of the guide bur (concentricity and run out), as increased run-out may lead to gross apical inaccuracy while drilling.
3. With the help of the guide, mark the entry point of the access through the sleeve with small bur on the enamel or on the restoration.
4. Remove the enamel or existing restoration free hand, without a guide. (To avoid over-heating, high-speed burs should not be used with the metallic sleeve).
5. After removing enamel, place the guide. Secure it with fingers or fixation screw.
6. Insert the guide bur in the sleeve drill and drill, cautiously, into the dentine. With this approach, we can achieve directed dentin conservation.
7. To avoid over-heating, drill in short and intermittent periods. Use copious amount of water coolant. Clean the bur (drill) properly after each stroke.
8. Start drilling with a short bur. After reaching the coronal third of the root, use long bur to reach the target point. With this method, improper angulation and wobbling of the long bur can be avoided.
9. After reaching the pre-planned depth, scout the canal. If canal cannot be negotiated, try to drill further into the canal. Once canal has been negotiated, carry out biomechanical preparation.

7.5 Potential Mishaps

i. Unstable Guide

Unstable endodontic guide may lead to complications such as over-extended cavity preparation or perforation of the tooth. Instability of endodontic guide can be attributed to multiple reasons:

- Faulty impression or faulty scanning

• Improper planning of the guide, for example over-sized offset: Offset is the space which is planned between the guide surface and the tooth which can be adjusted in the planning software. Based on our experience, 0.15 mm offset is ideal for posterior teeth. Guide can be stabilized by hands on both sides or incorporating surgical pins during planning or using chair-side composite.

ii. Inaccurate Drilling

Unnecessary removal of healthy tooth structure or perforation occurs due to inaccurate drilling. Following variables lead to inaccurate drilling:

- Artefacts on CBCT
- Unstable guide
- Dimensionally inaccurate bur and/or sleeve
- Faulty planning on the software Already accessed tooth can be difficult.

Already accessed tooth can be difficult. The access created, before guided approach, could slide the drill into different directions. To avoid this, create a small ditch or plateau at the bottom of the original access. Intra-coronal guide technique is also helpful to treat such cases. For implant placement, different drills and guide supports are required. In guided endodontics, we usually use tooth-supported guides and single or two drills. So, the accuracy of static guided endodontics is far better than guided implant placement in the literature[38]. With advent of shorter and smaller drills and advances in dynamic guidance technology, application of navigation for posterior teeth will get more acceptance.

VIII. DYNAMIC NAVIGATION

In many different areas of medicine, there is an increasing tendency of using computer navigated surgical, and therapeutic methods in the daily practice. In dentistry, these technologies were first adopted in dental implant surgery. The technology originating from implantology has reached other areas of dentistry, in particular, endodontics. Its potential uses include endodontic procedures such as trephination and root canal localization.

What Is 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). In dentistry, dynamic navigated surgery is placement of drill or implant, using real-time computer navigated system, based on the data generated from the patients' cone-beam computed tomography (CBCT).

8.1 Principles of Dynamic Navigation

Dynamic navigation system is in some way the same as a commonly used navigation system in a car. Both attempt to localize or determine a position in space in the context of its surroundings. The actual localization technology, however, differs as surgical navigation does not use triangulation like a global positioning system with the help of several geostationary satellites. 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 the basic setup, the requirements are a stereoscopic camera, a computer plat form 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, for example, 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.

Dynamic navigation is usually "image based:" it requires patient's radiographic data for navigation. To understand the navigation process, there are three terminologies we need to know.

1. Image acquisition: It means obtaining patient's radiographic data. CBCT imaging data (DICOM file) is used for navigation in dental treatments.

2. Planning: Before surgery, objects and areas of interest may be planned within the images and hence enrich the data sets.

3. Registration: Before the first drill is used, the preoperative image data need to be matched to the current patient position via a registration process. This is the process to establish a relation between the "real" co-ordinate system as defined by the patient's reference array and the "virtual" co-ordinate system of the imaging data. Registration can be paired point-based or use surface matching routines. It is also known as Tracing or trace registration. The surgeon, then, virtually sees both the current situation and the imaging datasets overlapped. After proper registration process, dynamic navigated treatment can be initiated.

In dentistry, implant positions and root canal locations can be designed and correlated with reference points with preoperative CBCT data and the help of computer software programs. 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[39]. 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. In summary, it facilitates the traceability of instrument position.

8.2 Dynamic Navigation Components and Workflow 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)

8.3 Workflow of Dynamic Navigation

To guide the drilling, navigation system must precisely map the drill tip to the CT image of the jaw used for planning the implantation. Sensors are attached on the body of the handpiece and the extraoral clip attached to the fiducial markers.

It achieves this in three steps, performed in the following order:

1. Trace Registration: CBCT images are matched with the teeth, through the Jaw Tracker or Head Tracker mounted on the patient, by registering the CBCT scan to the teeth and/or bone. For trace registration, a calibrated tracer (like a stylus pen or ball burnisher) tracked by the Micron Tracker camera is slid along the tooth surface, in brushing motion, while the system samples point along its path. The collected "cloud of points" is then automatically matched in the best possible way with the outer surface of the teeth in the CBCT scan. Minimum 3 and maximum 6 teeth can be traced for better accuracy. An accuracy check should be performed in all 3 directions (anteroposterior, laterolateral, and occlusogingival) to verify registration accuracy in all 3 axes.

2. Calibration: Mapping the drill tip to the DrillTag. The drilling axis calibration is done once, prior to the start of the operation by placing the handpiece chuck over a pin in the JawTag. After each drill change, the drill tip location is calibrated by touching a dimple on the calibrator.

3. Tracking: Mapping the DrillTag (Handpiece attachment) to the JawTag (Jaw attachement). This is dynamic and is done throughout the operation by the optical tracking system. Continuous tracking is very important to achieve planned treatment outcomes. Tracking camera should be placed at position to provide broad operating field view during the treatment. Extension arm of navigation device may help to achieve broad view of operating field.

8.4 Step-by-Step Workflow

1. Take a CBCT scan of the entire arch with high resolution and small field of view (FOV). Import scan data to dynamic navigation system.
2. Plan endodontic treatment on CBCT file in the dynamic navigation software. Plan virtual drill path for non-surgical treatment. Keep diameter of virtual path as minimal as possible (not more than 1.0 mm). For endodontic microsurgery, plan osteotomy site and size. Level and angulation of root end resection can also be planned, simultaneously.
3. Install the patient tracker (JawTracker or HeadTracker). It should be placed within range of camera tracking system. Endodontic microscope should be used carefully to avoid any errors during use of dynamic navigation.
4. Register the CBCT scan to the patient using Trace registration in one of the following ways:

(i) Tracing directly on the CBCT scan,
(ii) Using an intra-oral scan superimposed or matched with the CBCT scan,
(iii) Using the NaviBite (when the tooth and its neighbouring teeth have full coverage metallic restorations).

5. The patient tracker (JawTracker) 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.
6. Calibrate handpiece (slow-speed, high-speed or piezoelectric handpiece) and bur (drill) with calibrator. Registration accuracy should be evaluated before drilling.
7. 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.
8. For endodontic microsurgery, similar tracing and calibration has to be performed. Calibrate bone saw before use and also calibrate its dimensions for better accuracy. 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.

8.5 Advantages of Dynamic Navigation System

- CT scanning, planning, and surgery in a single appointment (when a CBCT is available on site)
- Reduced harm to the patient: minimally invasive surgery, leading to reduced patient discomfort, reduced risk of infection, and faster recovery
- Unintentional iatrogenic damage to nearby anatomical structures.
- Increased safety and predictability due to ability to verify guidance accuracy at any time
- Simpler and faster planning (no plaster models, wax-ups, and guide fabrication)
- Ability to view and modify the plan during the surgery, for example, to accommodate tactile feedback or unexpected complications
- Cost-effective. (Lower per-procedure costs)
- Improved irrigation, reducing risk of bone damage due to overheating
- No need of specialized equipment. Works with any implant or drill system
- Without sleeves, guidance is provided even when interocclusal or interdental space is limited
- Elimination of guidance failures due to fractured or badly fitting guides
- Improved ergonomics

8.6 Limitations

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. Every system has its own planning software; thus, one might not be able to use any other advanced software. Adequate learning is expected from the clinician as a learning curve is associated with it[40].

IX. Conclusion

Guided endodontics (GE) is an innovative method that uses 3D imaging (cone beam computed tomography, CBCT) and surface scans for minimally invasive access cavity preparation using virtual preoperative planning. A bur is guided to the planned position through a template sleeve system, similar to the guided implantology technique. It offers a safe and predictable method for locating calcified root canals. It also lowers the risk of iatrogenic damage. and proving it to be a highly promising technique. It represents a new perspective for complex endodontic cases, which could lead to errors in conventional procedures. Guided access techniques are more accurate and safe than traditional freehand technique. Guided endodontics with its predictable outcome, lower risk of procedural errors and preservation of structural integrity of tooth even in most challenging cases is soon going to be the future of endodontics.

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