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Comparative Analysis of Guided Endodontic Techniques: Dynamic Navigation vs Static Navigation

Integrative systematic review

Yacine BENALI

Dissertação conducente ao **Grau de Mestre** em **Medicina Dentária (Ciclo Integrado)**

—

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Trabalho realizado sob a Orientação de Professor Doutor Pedro Bernardino

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Eu, Yacine Benali, declaro ter atuado com absoluta integridade na elaboração deste trabalho, confirmo que em todo o trabalho conducente à sua elaboração não recorri a qualquer forma de falsificação de resultados ou à prática de plágio (ato pelo qual um indivíduo, mesmo por omissão, assume a autoria do trabalho intelectual pertencente a outrem, na sua totalidade ou em partes dele). Mais declaro que todas as frases que retirei de trabalhos anteriores pertencentes a outros autores foram referenciadas ou redigidas com novas palavras, tendo neste caso colocado a citação da fonte bibliográfica.

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RESUMO:

Introdução: A obliteração do canal pulpar é caracterizada pela formação de dentina terciária ao longo da parede do canal radicular, reduzindo o volume do espaço pulpar e o diâmetro do canal. A tecnologia moderna, como o acesso endodôntico guiado, melhorou a precisão no planejamento e tratamento de canais calcificados.

Objetivos: Analisar a precisão da navegação estática e da navegação dinâmica na técnica endodôntica guiada e explicar as vantagens e limitações desta técnica inovadora em casos difíceis de tratamento endodôntico.

Métodos: Foi realizada uma pesquisa eletrónica por palavras-chave na base de dados PubMed. Os critérios de inclusão aplicados foram artigos publicados nos últimos dez anos, em inglês, francês ou português, sobre a utilização de técnicas baseadas em computador em tratamentos endodônticos complicados.

Resultados: Dos 17 artigos, 12 discutiram a precisão e a eficiência da endodontia guiada na localização de canais calcificados. Dois focaram a sua fiabilidade na remoção de espigões de fibra. Um examinou as alterações de temperatura na superfície da raiz durante a utilização da broca guiada. Outro demonstrou o acesso guiado ao trajeto original do canal após desvio/perfuração. Por último, um artigo comparou duas técnicas de navegação assistida por computador.

Discussão: Segundo os resultados do estudo, o sistema de navegação dinâmico é uma técnica simples e eficaz que supera o sistema de navegação estático em termos de exatidão e precisão.

Conclusão: As técnicas são mais eficazes em comparação com os métodos tradicionais. No entanto, existem várias desvantagens e limitações associadas.

Palavras-chave: endodontia guiada, obliteração do canal pulpar, terapia do canal radicular, CBCT, limitações

ABSTRACT:

Introduction: Pulp canal obliteration (PCO) is characterized by the apposition of hard tissue (tertiary dentin) along the root canal wall, which results in a reduction in pulp space volume and root canal diameter. Nowadays, the use of modern technology, such as guided endodontic access, has increased the precision involved in planning and performing the treatment of calcified canals.

Objectives: Analyze the accuracy of the static navigation and the dynamic navigation in the guided endodontic technique and explain their advantages and limitations of these innovative technique in difficult cases of endodontic treatment.

Methods: A keyword-driven electronic search was conducted on the PubMed database. Articles published in the last ten years, in English, French or Portuguese, about the use of computer-based techniques in complicated endodontics treatments were the inclusion criteria applied.

Results: Of the 17 articles, 12 discussed guided endodontics' accuracy and efficiency in locating calcified canals. Two focused on its reliability in removing fiber posts. One examined temperature changes on the root surface during guided bur use. Another demonstrated guided access to the original canal path post-deviation/perforation. Lastly, one article compared two computer-aided navigation techniques.

Discussion: According to the study's findings, the dynamic navigation system is a straightforward, effective technique that outperformed the static navigation system in terms of accuracy and precision.

Conclusion: More Effective compared to traditional methods, these two procedures enable the preservation of dental structures. However, there are several disadvantages and limitations associated with these techniques.

Keywords: guided endodontics, pulp canal obliteration, root canal therapy, CBCT, limitations

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ABBREVIATURES:

3D – 3-Dimensionnal

ACP – Access Cavity Preparation

ASA – American Society of Anesthesiology

BL – Bucco-Lingual

CAD-CAM – Computer-Aided Design/ Computer-Aided Manufacture

CBCT – Cone-Beam Computed Tomography

CEJ – Cement-Enamel Junction

CONV- Conventional

DICOM – Digital Imaging and Communications in Medicine

DNS – Dynamic Navigation System

FH – Freehand

G - Group

GE- Guided Endodontics

MD – Mesio-Distal

PCO – Pulp Canal Obliteration

RCT – Root Canal Treatment

RTGE – Real Time Guided Endodontics

SNS – Static Navigation System

STL – Stereolithographic

TDI – Traumatic Dental injuries

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1. INTRODUCTION:

A proper access to the root canals is one of the most challenging and frustrating aspects of endodontic treatment, since such a procedure has a direct effect on the location, preparation, and obturation of the root canal system (1). Among the treatment objectives of root canal treatment (RCT) is the need to preserve normal periradicular tissues. RCT is performed by removing pulp, precise shaping, and cleaning the root canal with the aim of eliminating microorganisms in the root canal system (2). Teeth exhibiting pulp canal obliteration (PCO), or calcified canals often require a challenging and time-consuming endodontic treatment. It generally has no symptoms and can be detected via tooth discoloration and/or radiographical examination. (3)

PCO is characterized by the apposition of hard tissue (tertiary dentin) along the root canal wall, which results in a reduction in pulp space volume and root canal diameter. Tertiary dentin is deposited in response to injury (e.g., traumatic injuries, caries, orthodontic therapy, etc) because of the pulp healing process. It may lead to partial or complete PCO. PCO is common in young permanent teeth following luxation injuries, though the frequency of PCO varies in the clinical literature from 3,7 to 40 % after traumatic dental injuries (TDI) and from 29.4% to 95.2% after root fractures. Root canal calcification may be also caused by pulp aging processes due to the lifelong physiological apposition of secondary and tertiary dentine. The number of elderly patients who need RCT is increasing. (2)

The goals of endodontic treatment may not be achieved in cases of partial or total obliteration of pulp spaces. Although many approaches to treat calcified canals have been described, even the most experienced endodontists can face difficulties in reaching patency and performing the proper cleaning and shaping. (4)

Nowadays, the use of modern technology, such as magnification and illumination with a dental operating microscope, ultrasonic tips, cone beam-computed tomographic (CBCT) imaging, and guided endodontic access, has increased the precision involved in planning and performing the treatment of calcified canals as well as allowed practitioners to overcome some of these challenges. (5)

Guided endodontics, either with computer-aided static (SNS) or dynamic navigation (DNS) techniques, has recently emerged as an alternative for access cavity preparation in the clinical management of complex cases. (3)

The guided endodontics was inspired from surgical guides used in implantology. These guides accurately delimit the trajectories of the drills for implants placement, and currently, may be used for endodontic applications. Prior to the guide fabrication, a CBCT and an intraoral digital scanning of the dental region, which includes the tooth to be endodontically treated, are performed. With the aid of a software which aligns the archives obtained from the CBCT and the intraoral scanning, the guide is digitally planned. Next, a 3D-guide of rigid material is printed, which it will fit on the tooth surface, allowing the drill to access the root canal with less risks of deviation (1).

Dynamic navigation with passive optical technology that has been used in implant dentistry in recent years uses a computer to guide implant placement in real time based on information gathered from a CBCT image. Motion tracking enables the system by following the position of both the patient and the dental handpiece throughout the procedure. The ideal drill position is planned virtually by the surgeon using the CBCT data set uploaded into the planning software. (6)

2. OBJECTIVES AND HYPOTESIS:

The main objective of this study is to analyze and compare the accuracy of the static navigation and the dynamic navigation in the guided endodontic technique in dental practice.

The second objective is to explain their advantages and limitations of these innovative technique in difficult cases of endodontic treatment.

By synthesizing the available evidence from published studies, we aim to provide a comprehensive assessment of the outcomes of these two types of treatment and determine which approach may be more effective for the patients.

The null hypothesis considers that "there is no difference between SNS and DNS regarding the accuracy and conservation of tooth structure and therefore both techniques have the same advantages and limitations".

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3. MATERIAL AND METODS:

3.1. Protocol

This study was realized in agreement with the directives PRISMA (Preferred Reporting Items for Systematic and Meta-Analyses).

3.2. Eligibility criteria

This work was recommended according to Cochrane's recommendations responding to PICO (Population; Intervention; Comparison; Outcome).

Patients:	Patients with PCO, or patients presenting an apical periodontitis who need an endodontic canal treatment with complex access to the teeth, or patients with fiber posts allowing for a more predictable retreatment of the root canal.
Intervention:	Dynamic or static approaches in guided endodontics
Context:	Compare the different guided endodontic techniques.
Outcome:	Accuracy, iatrogenic errors, time taken, advantages and limitations.

Table 1: PICO strategy

The eligibility criteria were divided into two groups, the inclusion and exclusion criteria:

Inclusion criteria:	**Exclusion criteria:**
○ Use of computer-aided technologies in complicated endodontics cases. ○ Articles in English, Portuguese, French. ○ Ex vivo studies, in vitro studies, case reports	○ Use of computer-aided technologies in implantology, bone regeneration, periodontology, or laser therapy. ○ Articles that have more than 10 years, and systematic reviews with or without meta-analysis. ○ Books and documents. ○ Duplicates

Table 2: Eligibility criteria

3.3. Searching for information

This literature search was conducted in the PubMed databases (via the National Library of Medicine) between April 2013 and April 2024 with the combination of the following scientific MeSH terms: " Cone beam computed tomography", " Root canal therapy", " Dental pulp cavity ", " Guided endodontics ", " Dynamic navigation".

Advanced search:

Advanced search:	Results
(endodontics[MeSH Terms]) AND (guided)	467
((guided endodontics) AND (cone beam computed tomography[MeSH Terms])) AND (dental pulp cavity[MeSH Terms])	47
((guided) AND (dental pulp cavity[MeSH Terms]) AND (root canal therapy[MeSH Terms])) AND (cone beam computed tomography[MeSH Terms])	30

Table 3: PubMed advanced search results

Other supporting articles for the introduction and discussion were obtained with a free manual search.

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4. RESULTS:

4.1. Selection of articles:

The initial search in the available database returned a total of 544 articles which 79 duplicates were excluded. On the remaining 469 articles, the titles and abstracts were read seeking in accordance with the inclusion and exclusion criteria of the present study. 15 papers were discarded after full article reading, because they did not include significant information about the different existing guided endodontics methods. The evaluation of titles and abstracts resulted in the selection of potentially 20 studies of which 3 were excluded after full article reading regarding lack of available data. The results of articles are shown in Figure 1.

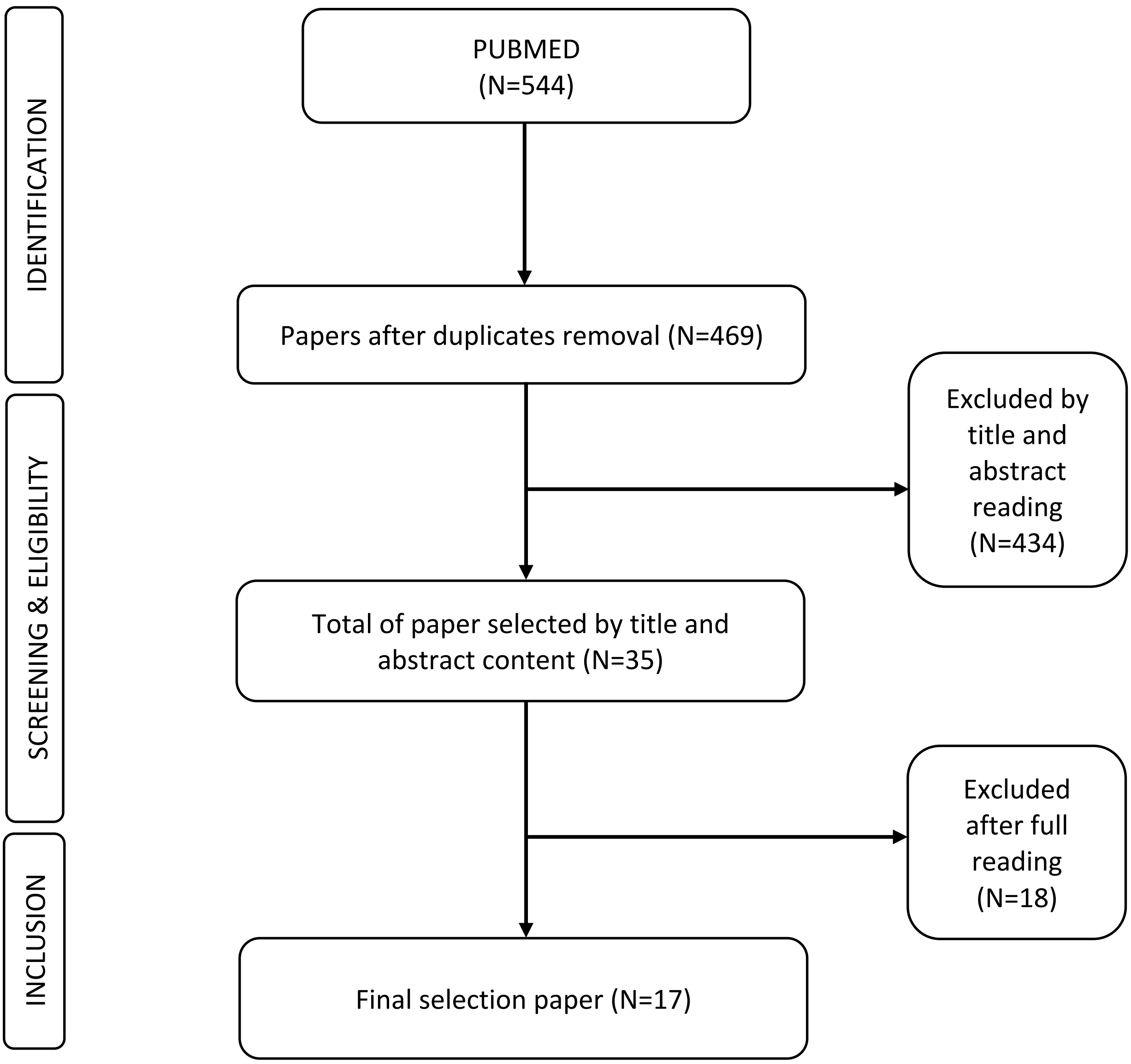

Figure 1: Flow diagram of the search used in this study.

4.2. Characteristics of the studies:

4.2.1. Year of publication

In terms of the publication period, 2020 had the greatest number of articles on the subject, with six (34%), followed by 2022 with six (22%), in 2021, three articles (18%) were published. While in 2019, two (12%) papers. Whereas in 2018 and 2015 just one (6%) article was issued. The distribution with respect to the years of publication is shown in Figure 2.

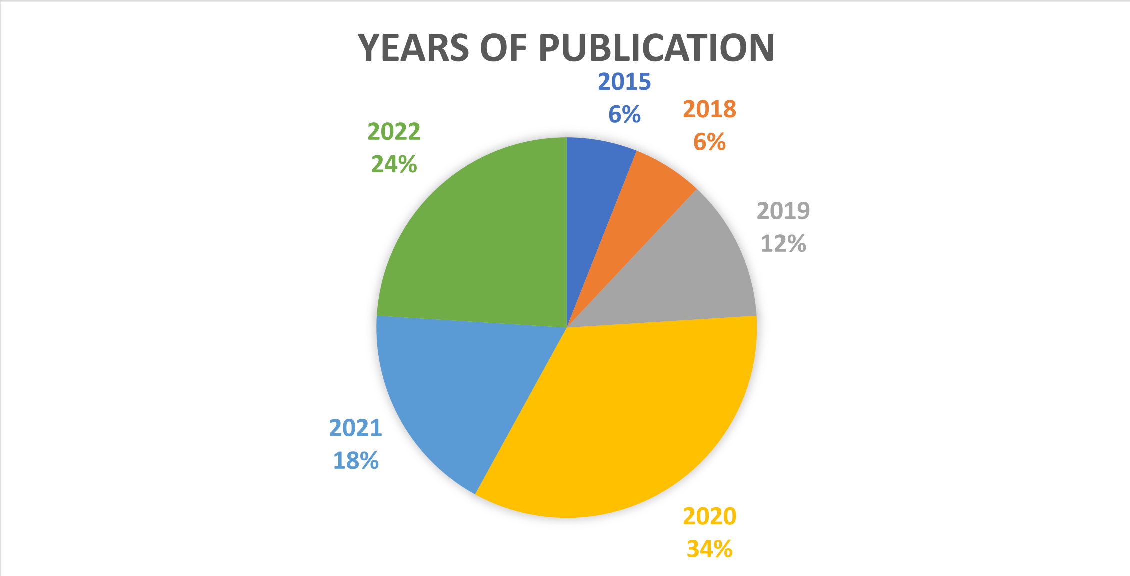

Figure 2: Distribution by year of publication of the articles included.

4.2.2. Type of studies:

Considering the type of studies of the articles presented, seven papers (41%) are ex-vivo studies, six (35%) are case reports, three (18%) are in-vitro studies, and one (6%) is an observational study.

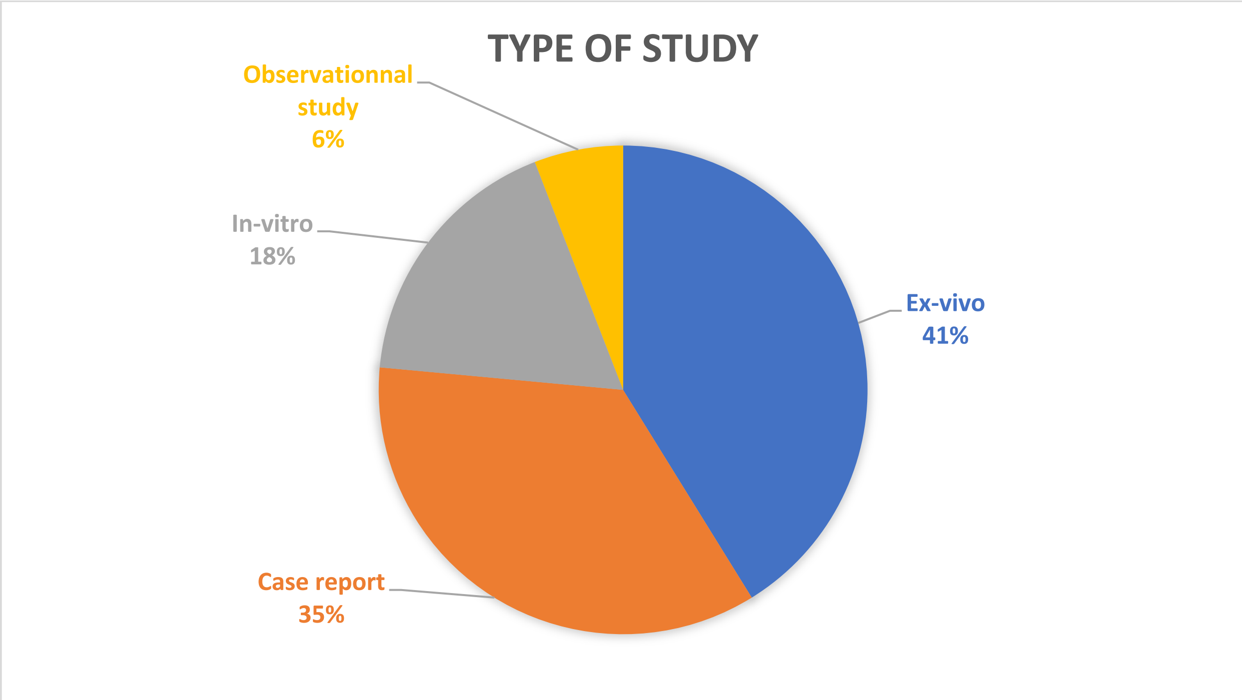

Figure 3: Distribution according to the type of study.

4.2.3. Main objective of studies:

Out of the 17 studies included in this review, 12 (70%) studies discussed the accuracy and efficiency of the guided endodontics (GE) technique to locate calcified canals. 2 (12%) studies assessed the reliability and effectiveness of the guided technique to locate and remove fiber posts. 1 (6%) study evaluated the temperatures changes of the root surface when a bur is used in the guided technique. One (6%) paper showed the use of guides to access the original canal path after an occurrence of deviation and perforation. One (6%) article analyzed and compared the two existing computer-aided navigation techniques.

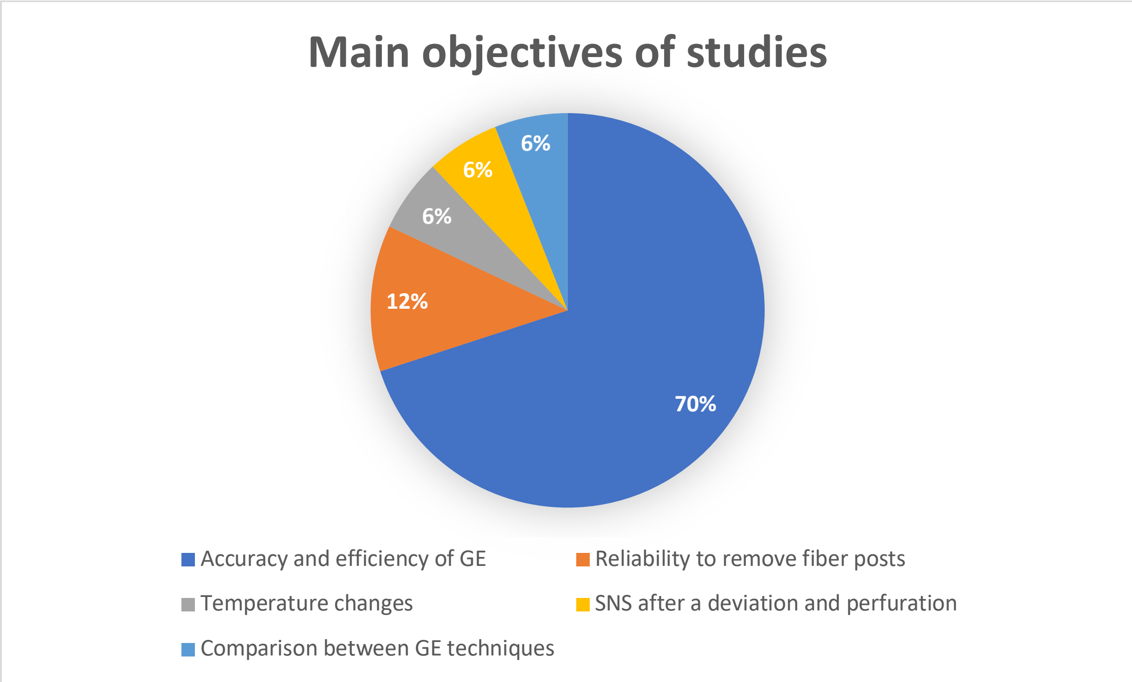

Figure 4: Distribution according to the main objective of studies.

Table 4: Relevant data gathered from the selected studies:

Title, author, year, and type of study	Purpose	Material and methods	Protocol	Results	Conclusions
Guided access cavity preparation using cone-beam computed tomography and optical surface scans – an ex vivo study **Buchgreitz et al. (2015)** (7)	To evaluate ex vivo, the accuracy of a preparation procedure planned for teeth with PCO using a guide rail concept based on a CBCT scan merged with an optical surface scan.	48 teeth embedded in 12 acrylic blocks.	<u>Virtual design of the drill path:</u> **CBCT scan** (Orthophos XG 3D unit, Sirona Dental Systems, Bensheim, Germany) **Virtual drill path:** 1.2 mm **Virtual sleeve:** diameter of 1.4 mm, length of 4mm. <u>Guide rail construction:</u> **3D scan** (CEREC, Sirona Dental Systems) **Guide rail** produced by CNC technology as a SICAT optiguide (SICAT, Bonn, Germany) **Bur:** diameter of 1.2 mm, working length of 22 mm.	Null hypothesis H0: I = 0.7: rejected (CI 95%: 0.31;0.49, P < 0.001) The mean distance between the drill path and the target was significantly lower.	The combined use of CBCT and optical scans for the precise construction of a guide rail leads to a drill path that will reach an apical target point. The presented technique may be a valuable tool for the negotiation and instrumentation of partial or complete PCO.
Guided root canal preparation using cone beam computed tomography and optical surface scans – an	To report the precision of guided access cavity preparations in relation to demographical and dental variables in 50 patients.	50 patients, (30 W, 19 M) <u>Inclusion criteria:</u> - consecutively referred patients with pulp space obliteration associated with signs of apical periodontitis (PAI score >3 or sensitive to percussion.	<u>Virtual design drill path:</u> - **A CBCT scan** (Orthophos XG 3D unit, Sirona Dental Systems, Bensheim, Germany) - **Drill path:** diameter of 1.2 mm. <u>Guide construction:</u>	Length of pulp space obliteration was greater in maxillary compared with mandibular teeth. **Performance of the drill path in mandibular teeth**: greater number of optimal precision scores. **Precision of the drill path** resulted in significantly more optimal scores when a	It was possible to demonstrate that guided access cavity preparation and canal location and negotiation using CBCT in combination with optical surface scans provided an

observational study of pulp space obliteration and drill path depth in 50 patients. **J. Buchgreitz et al. (2018)** Observational study (8)		- teeth with pulp space obliteration in need of a post. - a surgical intervention was not justified. <u>Exclusion criteria:</u> - neighboring teeth with metal restorations leading to CBCT artefacts. the tooth could not be retained in a stable and rigid position during the scanning procedure and access preparation (n=1 pacient).	- Teeth were **surface scanned** (CEREC, Sirona Dental Systems) - **Virtual surface** models were **merged** with the **CBCT** (Galaxis/Galileos Implant, Sirona Dental Systems), - metal sleeve was produced by CNC technology as a SICAT optiguide (SICAT, Bonn, Germany) <u>Drill path:</u> - **Spiral bur** of diameter of 1.2 mm (Busch, Engelskirchen, Germany) - Low-speed drilling was performed at 250 rpm (VDW Silver, Munich, Germany).	previous attempt at access and canal negotiation had occurred versus no attempt. **The hypothesis was confirmed** that guided drill paths have sufficient precision regardless of age, gender, previous treatment status, length of pulp space obliteration as well as previous attempts to negotiate the root canal.	overall optimal or acceptable precision in single-rooted anterior teeth with pulp space obliteration.
Guided Endodontics in Complex Scenarios of Calcified Molars **Tavares W et al. (2019)** Case report (4)	Report a case series and describe the use of guided endodontics in complex symptomatic cases of mandibular and maxillary molars; presenting calcification of all three root canals.	<u>Case 1:</u> - 33-year-old male patient. - Pain in the mandibular right second molar. - Mesial root presented partially calcified canals and false entrance orifices. <u>Case 2:</u> - 45-year-old female patient. - Pain in the first right mandibular molar. - Presence of canal calcification and the canals converged to a single foramen. <u>Case 3:</u> - 42-year-old female patient.	**3D scan** (3 Shape Trios 3-Color Intraoral Scanner; Holmens Kanal, Copenhagen, Denmark) **CBCT scan** using the settings: 0.2-mm voxel, grey scale, 14 bits, 26.9-sec X-ray exposure, 120 kV, and 37 mA (iCAT; Imaging Sciences International, Hatfield, PA, USA) **Drill path:** Diameter 1.3 mm and length of 20 mm (Neodent Drill for Temp Implants, Ref: 103179; JJGC Ind e Comércio de Materiais Dentarios SA, Curitiba, Brazil) **3D printer** (Formlabs2, Formlab Inc., 35 Medford St. Suite 201, Somerville, MA 02143, USA).	In all cases at the 12-month follow-ups, the patients were completely asymptomatic.	This case series study revealed the use of guided endodontics in cases of calcification in molars could be a viable and reliable alternative treatment.

		- First right maxillary molar presented acute apical periodontitis. Complete obliteration of all the canals	**Endodontic motor** set at 900 rpm and 4 N torque. In the **third case**, it was necessary to build 3 different templates, one designed for each canal.		
Computer-aided dynamic navigation: a novel method for guided endodontics **Chong B. et al (2019)** Ex vivo study (9)	Investigate the novel use of computer-aided DNS for guided endodontics.	29 extracted human tooth: six central incisors, two lateral incisors, three canines, three first premolars, eight second premolars, five first molars, and two second molars. The teeth were set-up in individual molds and plaster was poured into it to create three dental casts.	- Preoperative CBCT and periapical radiograph of each cast - Black and white jaw tag (tracing-array) + casts monted in a phantom head - Black and white array attached to the handpiece. - diamond burs to breach the enamel, and round stainless-steel burs (ISO 330 206 698 001 160, Hager & Meisinger) for the dentin.	- Conservative access cavities were achieved and all the canals of 26 teeth (n = 29) were successfully located. - Tracking difficulties were encountered with three molar teeth; only one (palatal) canal each was successfully located in two maxillary (right and left) second molars; in a maxillary left first molar, only two canals (mesiobuccal and palatal) were successfully located and the access preparation for the third canal (distobuccal) was misaligned and off-target.	This study demonstrates the potential use and feasibility of transferring computer-aided DNS technology to endodontics, to guide and facilitate access cavity preparation and root canal location.
Accuracy and Efficiency of a Dynamic Navigation System for Locating Calcified Canals **Dianat O. et al. (2020)** Ex vivo study (6)	Compare the accuracy and efficiency of a DNS to the freehand (FH) method for locating calcified canals in human teeth.	Sixty human single-rooted teeth (maxillary and mandibular incisors, canines, and premolars) with PCO. Teeth mounted with polyvinyl siloxane bite registration material (Regisil Rigid; Dentsply Sirona Restorative, York, PA) in dry cadaver maxillae and mandibles into their corresponding anatomic positions.	- **CBCT scan** (CS 9300; Carestream LLC, Atlanta, GA) was taken at 0.090-mm resolution. - A small thermoplastic device (X-clip, X-Nav Technologies, LLC) with 3 radiopaque fiducial markers was molded to molars on 1 side of the arch. The X-clip held the dynamic reference frame or tracking devices during access cavity preparation. -The Digital Imaging and Communications in Medicine (DICOM) data set from the CBCT scan was uploaded to the DN planning software, and the drilling entry point, angle,	The mean required drilling depth in the DN and FH groups showed no statistically significant difference. The root canals were successfully located in 96.6% (29/30) of the samples in the DNS group and in 83.3% (25/30) of the samples in the FH group. **Linear deviation** in DNS: -BL (Bucco-lingual): 0,19 mm -MD (Mesio-distal): 0,12 mm **Linear deviation** in FH: - BL: 0,81 mm -MD: 0,31 mm	The DNS was more accurate and more efficient in locating canals in calcified human teeth compared with the FH technique. This novel system resulted in significantly less tooth structure removal and a shorter operation time.

			pathway, and depth of drills were virtually planned **- Bur:** round diamond bur using a high-speed handpiece followed by a size #1 (0.8 mm) Munce bur (CJM Engineering Inc, Ojai, CA) on a slow- speed handpiece at 5000 RPM - postoperative CBCT scan	**Angular deflection** - DNS = 7,25° - FH = 2,39° **Reduced enamel** - DNS =1,06 mm Cement -enamel Junction (CEJ), 1,15 mm (end drilling point) - FH = 1,55 mm (CEJ), 1,47 mm (end drilling point) **Time required for access cavity preparation:** - In DNS between 1 min 31 s and 10 mins and a mean of 3 min and 47 s. - In FH, between 1 min and 24 s and 19 min and a mean of 6 min and 45s.	
3-Dimensional Accuracy of Dynamic Navigation Technology in Locating Calcified Canals **Jain S. et al. (2020)** Ex vivo study (10)	Present a novel dynamic navigation method to attain minimally invasive access cavity preparations and to evaluate its 3-dimensional (3D) accuracy in locating highly difficult simulated calcified canals among maxillary and mandibular teeth.	Stereolithographic images (STL) were generated of anatomically precise human teeth replicas (TrueTooth; DELendo, Santa Barbara, CA) including anteriors, bicuspids, and molars. Three identical sets of maxillary and mandibular jaw models composed of 84 teeth were 3D printed.	The Navident protocol was performed in 4 steps: **1. Scan**: a preoperative CBCT scan (CS 8100 3-D; Carestream Health Inc, Rochester, NY) with a minimum voxel size of 75 mm was performed separately for each of the jaw models and stored as a Digital Imaging and Communications in Medicine (DICOM) file. These files were imported into the Navident (ClaroNav, Toronto, Ontario, Canada) implant/access planning software to map the dentition. **2. Plan:** the CBCT image data served as a guide to plan nonsurgical virtual 3D access cavity/paths of 1.0-mm diameter and depths ranging from 9.5–21 mm. The entry point started from the incisal edge/occlusal table to the point of negotiation of the canals in 3 dimensions. Each canal was entered through its own access opening. For instance, upper	- **Average drilling time** = 57.8 seconds, dependent on the canal orifice depth, tooth type, and jaw. For a 1-mm increase in the canal orifice depth, the drilling time increased by 7.6 seconds. - **Average canal orifice depth** = 12.4 mm. - **Overall mean 3D deviation** from the canal orifice = 1.3 mm. - **Mean 3D angular deviation** = 1.7° - **Mean 2D entry, horizontal and vertical deviation** from the canal orifices were 1.1, 0.9, and 1.0 mm respectively. - **The 2D entry deviations** were higher on the mandible: 1.23 vs 0.85 mm.	Optically driven, computer-aided, 3D dynamic navigation technology with high-speed drills can achieve minimally invasive access cavities in locating highly difficult simulated calcified canals with mean 2D horizontal deviation of 0.9 mm and a mean 3D deviation of 1.3 mm from the canal orifice, and a mean 3D angular deviation of 1.7°

			molars with 4 canals ended up with four 1-mm openings in their occlusal surfaces. **3. Trace:** the CBCT images were matched with the mounted TrueJaw, through the Jaw Tracker installed on it, by registering the CBCT scan to the model. The matching is done through the "trace registration" technique; a calibrated tracer (like a stylus pen) tracked by the Micron Tracker camera is slid along the tooth surface 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. A full accuracy check was performed in all 3 directions (anteroposterior, laterolateral, and occlusogingival) to verify registration accuracy in all 3 axes. **4. Place** (navigated access): each jaw was mounted onto a dental manikin. A latex face with limited mouth opening simulated limited visibility and pressure caused by facial soft tissues. Teeth were isolated using a dental dam. Navigated access cavity preparation for canals within a jaw set was performed in a randomized order. Precision microendodontic (tip diameter = 0.28 mm) high-speed access burs (Endoguide EG3; SSWhite, Lakewood, NJ) were used for the initial access in combination with surgical- length (tip diameter = 0.21 mm) Tapered diamond carbide burs (859 FGSL; KometUSA, Rockhill, SC) for the remaining depth of the access cavity preparation.	- **2D horizontal deviation** for the maxillary was 0.97 mm compared with 0.70 mm on the mandibular, with an average difference of 0.27 mm. - **3D canal orifice deviation**, higher on the maxilla at 1.4 mm compared with 1.2 mm for the mandible. Average deviation for molars was 1.9°, significantly higher than the 1.4° mean for premolars.	

Dynamically Navigated versus Freehand Access Cavity Preparation: A Comparative Study on Substance Loss Using Simulated Calcified Canals **Jain S. et al. (2020)** In vitro study (11)	Compare the speed, qualitative precision, and quantitative loss of tooth structure with FH and DNS access preparation techniques for root canal location in 3-dimensional–printed teeth with simulated calcified root canals.	Anatomically precise maxillary and mandibular single-rooted central incisors (n = 40) were custom 3D printed (TrueTooth; DELabs, Santa Barbara, CA) to simulate pulp canal obliteration. The experimental teeth were individually mounted according to their anatomic position in a maxillary or mandibular ModuPRO Endo model (Acadental, Overland Park, KS) to simulate a partially dentate jaw. All the teeth were mounted using a puttylike material (Splash! Putty; DenMat, Lompoc, CA). A latex face with a limited mouth opening was used to cover the jaw model setup to simulate limited visibility and pressure due to facial soft tissues. Teeth were isolated using a dental dam. The following burs were available for use with a high-speed handpiece for freehand and dynamic access preparations: a surgical length #2 round bur (Coltene, Altst€atten, Switzerland), an 859 FGSL bur (Komet USA, Rock Hill, SC), and an EndoZ bur (Dentsply Sirona, York, PA). Limited field of view CBCT scans taken with the CS 8100 3-D unit (Carestream Health Inc, Rochester, NY) were obtained for all mounted treatment teeth with the following exposure	<u>**Freehand Acess Cavity Preparation:**</u> Limited field of view CBCT scans were available to view during the freehand access procedures to aid in assessing angulation and measurements. The design for preparations in both maxillary and mandibular incisors started away from the cingulum and extended toward the incisal edge. The accesses were performed under a dental operating microscope (Global Surgical Corporation, St Louis, MO). The time of each access preparation was recorded from the initial preparation of the tooth structure to the point of successful canal negotiation or when the operator suspected the access depth to reach the estimated measurement to the canal space. <u>**Dynamic Navigation Access Cavity Preparation:**</u> Access cavities were made under full guidance of the second-generation Navident (ClaroNav, Toronto, Ontario, Canada) workflow (ie, scanning, planning, tracing, and placing [dynamically navigated access]) as described by Jain et al. The time of each access preparation treatment was recorded to the point at which the bur reached the end of the planned drill path. A periapical radiograph of the tooth with a #15 K-file (Dentsply Sirona) within the access/canal confirmed successful canal location.	<u>**Quantitative Substance Loss:**</u> - Dynamically navigated accesses resulted in significantly less mean tooth substance loss in comparison with the conventional freehand technique: 27.2 vs 40.7 mm^3. - The amount of substance loss in the maxillary teeth averaged 35.5 mm^3 using dynamic navigation, which was significantly higher than the amount removed for the mandibular teeth. - The mean substance loss for the freehand technique in the maxillary teeth was 62.2 mm^3, which was significantly higher than any other groups. - The average amount of tooth structure removed in the maxillary teeth using the freehand technique was on average 26.7 mm^3 more for the dynamic navigation group. - The difference between access techniques for the mandibular teeth was negligible (19.1 mm^3 and 19.0 mm^3, respectively), with an average difference of 0.14 mm^3. <u>**Qualitative Precision:**</u> - Dynamically navigated accesses were associated with higher optimal precision (drill path centered) to locate calcified canals	Within the limitations of this in vitro study, overall, DNS access preparations led to significantly less substance loss with optimal and efficient precision in locating simulated anterior calcified root canals in comparison with FH access preparations.

		parameters: a 60- kV peak, 2.0 mA, 15.0 seconds, and a 75-mm voxel size.	In case of a suspected perforation or inability to access the canal in any group or under any circumstance, the operator was allowed to stop the treatment.
			Substance loss was quantified using postoperative CBCT scans that were analyzed with the ITK-SNAP DICOM viewer. It enables semiautomatic segmentation of the plastic tooth structure in the foreground, whereas lower threshold values can be used to exclude the prepared canal in the background. Automatic active contour evolution by ITK-SNAP helps analyze the volume of the substance loss and prepare 3D rendering models of the prepared tooth.
			
			Additionally, 2 board-certified endodontists independently and blindly analyzed the models for qualitative assessment of the access cavity preparation. The completed access drill paths were classified as 1 of the following:
			
			1. Optimal precision: a centrally located drill path in relation to the root canal with location and negotiation of the root canals possible.
			2. Suboptimal precision: a peripheral or tangentially transported drill path in relation to the root canal with location and negotiation of the root canals possible.
			3. Unacceptable precision: a peripheral or tangentially transported drill path in relation to the root canal deeming the tooth nonrestorable because of perforation or the inability of the
				in comparison with the freehand technique (75% vs 45%).
				
				- Freehand access group was associated with higher instances of suboptimal precision (tangentially transported) to locate calcified canals (40% vs 15%), especially in the maxillary teeth.
				
				- Among the 3 instances of unacceptable precision for the freehand group, 2 were associated with perforations in each jaw.
				
				- There was 1 instance of unsuccessful canal location and perforation within the dynamic navigation group.
				
				- The access techniques relating to unacceptable precision (ie, the inability to locate the canal and/or perforation) were not statistically significant (15% vs 10%).
				
				<u>Treatment Duration for Locating Calcified Canals:</u>
				
				- Dynamically navigated group:
				  ○ Maxila = 164.8 s (101.1–228.4)
				  ○ Mandible = 107.5 s (76.6–138.4)
				  ○ Mean= 136.1 s (101.4–170.8)
				
				- Freehand group:	

			operator to locate and negotiate the root canals.	○ Maxila = 598.8 s (370.0–827.6) ○ Mandible = 250.8 s (190.6–311.0) ○ Mean= 424.8 s (289.4–560.2)	
Guided Endodontics for Managing Severely Calcified Canals **Pujol M. et al. (2020)** Case report (12)	Describe guided endodontics in managing 7 severely obliterated teeth using both virtually designed 3D guides and a customized 1-mm-diameter cylindrical bur.	Seven consecutive adult patients (aged 27–53 years, mean age = 40.5 years). History of dental trauma experiencing tooth discomfort in the anterior region. Apical lesion in 6 of the 7 teeth and advanced PCO in all the teeth	**Radiographic examination**, which a periapical radiograph (Kodak RVG 6100; Carestream Health, Rochester, NY) **CBCT scan** (Newtom 5GXL; Newtom, Verona, Italy) **intraoral scan** (Trios3; 3Shape, København, Denmark) **Bur length:** 12 mm **Bur diameter**: 1mm <u>Guide construction:</u> **3D printer:** extrusion-based 3D printer (FDM), photopolymerization-based 3D printer (SLA).	No patients reported discomfort upon percussion or palpation at least 1 year after the treatment when periapical healing was evident.	Guided endodontics was demonstrated to be a safe, accurate, and conservative approach for the endodontic management of severely anterior obliterated canals when precise virtual planning is used. CBCT imaging should be used to determine the need for guided endodontic access depending on the degree of tooth obliteration.
Access to original canal trajectory after deviation and perforation with guided endodontic assistance **Casadei B. et al. (2020)**	Describes an endodontic treatment where there was an intercurrence, generating deviation and perforation, which was solved with the aid of	Female patient, 37 years old, ASA1 (American Society of Anestesiology) Calcified canal of the second right upper premolar Diagnositc : chronic periapical abscess	**CBCT scan:** 0.12-mm voxel (iCAT; Imaging Sciences International, Hat- field, PA) **Intraoral scan:** (Trios 3 COLOR, 3SHAPE Holmens Kanal 7,4.1060 Copenhague K Dinamarca) **Virtual bur:** with a <u>working length of 12mm</u> and <u>diameter of 1.3 mm</u> (Neodent Drill for Tempimplants, Ref.: 103179; JJGC Ind. e Comercio de Materiais Dentarios SA, Curitiba, Brazil)	The patient remained asymptomatic, and the tooth was rehabilitated with protease c after 20 days. One year after the conclusion of the case, regression of the periapical lesion was observed, as well as absence of painful symptoms and a negative response to clinical tests.	The guided endodontic technique favoured the resumption of the original anatomical trajectory after conventional endodontic treatment without success in a severely calcified

Case report (13)	guided endodontics.		Guide construction: **Stainless steel sleeves** 3.0 mm external diameter, 1.4 mm internal diameter and 8 mm length **3D printer** (Objet Eden 260 V with FullCure 720; Strata- sys Ltd, Minneapolis, MN).		canal. The guided access allowed for the drill to penetrate with the proper angulation and direction to the visible light point of the canal located in the CBCT.
Accuracy of Computer-Aided Dynamic Navigation Compared to Computer-Aided Static Procedure for Endodontic Access Cavities: An In Vitro Study **Zubizarreta-Macho A. et al. (2020)** In vitro study (14)	To analyze the accuracy of two computer-aided navigation techniques to guide the performance of endodontic access cavities compared with the conventional access procedure.	30 single-rooted anterior teeth **Group A:** guided performance of endodontic access cavities using computer-aided static navigation system (NemoScan®, Nemotec, Madrid, Spain) (*n* = 10) (SN) **Group B:** guided performance of endodontic access cavities using computer-aided dynamic navigation system (Navident, ClaroNav) (*n* = 10) (DN) **Group C:** manual (freehand) performance of endodontic access cavities (*n* = 10) (MN)	SNS group: **CBCT scan** (WhiteFox, Acteón Médico-Dental Ibérica S.A.U.-Satelec, Merignac, France) with the exposure parameters: 105.0 kilovolt peak, 8.0 milliamperes, 7.20 s, and a field of view of 15 × 13 mm. **3D surface scan** (EVO, Ceratomic, Protechno, Girona, Spain). **Virtual bur:** diameter 1.2 mm, working length 11mm. **3D printer** using stereolithography technique (ProJet® 6000, 3D Systems©®, Rock Hill, SC, USA). **Bur:** diameter 1.2 mm, working length 11mm (Ref. 882 314 012, Komet Medical, Lemgo, Germany). DNS group: preoperative **CBCT scan**	The null hypothesis (H0), which is that there would be no difference between the accuracy of endodontic access cavities performed through static and dynamic navigation systems compared with the conventional technique is accepted.	Within the limitations of this study, our results show that computer-aided static and dynamic navigation procedures allow more accurate and safe endodontic access to cavities than conventional freehand techniques.

			Thermoplastic template (NaviStent, Navident, ClaroNav) Black-and-white drill tag attached to the high-speed handpiece. Laptop computer of the aided computer-aided dynamic navigation system (Navident, ClaroNav). Diamond bur surface (Ref. 882 314 012, Komet Medical, Lemgo, Germany).		

Accuracy and Efficiency of 3-dimensional Dynamic Navigation System for Removal of Fiber Post from Root Canal–Treated Teeth
 	
Janabi A. et al. (2021)
 	
Ex vivo study
 	
(15)
	Investigate the accuracy and efficiency of the 3-dimensional DNS compared with the FH when removing fiber posts from root canal–treated teeth.	Twenty-six freshly extracted human maxillary single-rooted teeth (maxillary canines and incisors). With inclusion criteria: sound teeth, single-rooted teeth with straight canals, the presence of a single canal verified radiographically, complete root development, and teeth with at least a 15-mm root length.
		
		Root canal preparation was performed with a crown-down technique using HyFlex Rotary Files. The canals were instrumented up to a size #40/.06 and irrigated with 5 mL 2.5% sodium hypochlorite between the files.
		The root canals were dried with paper points (Dentsply Sirona) and obturated with a corresponding 40/.06 gutta-percha point (Coltene/Whaledent) and AH Plus sealer (Dentsply DeTrey GmbH, Konstanz, Germany) using a single-cone technique.
			Two extracted human maxillary molars (#14 and #15) were mounted on the left side, and teeth #2 and 3 were mounted in the right side of the maxilla to fix an X-clip (X-Nav Technologies, Lansdale, PA).
			Before the preoperative CBCT scan, the X-clip with 3 radiopaque fiducials was molded to molar areas according to the manufacturer's instructions for the DNS group. The X-clip was left in position on the opposite side from the procedure in the opposing arch.
			A single-arch CBCT scan (CS 93000; Carestream, Atlanta, GA) was taken at 0.120-mm3 voxel size resolution.
			
			<u>DNS group:</u>
			
			- The Digital Imaging for Communication in Medicine data set was uploaded into the X-guide software (X-Nav Technologies) and entered into the DNS planning system. The drilling entry point, angle, trajectory, and
				<u>**Dynamic navigation group:**</u>
				
				- **Global coronal deviation:** 0.91 ± 0.65 mm
				- **Global apical deviation:** 1.17 ± 0.64 mm
				- **Angular deflection:** 1.75° ± 0.63°
				- **Operation time:** 4.03 ± 0.43 min
				- **Volume of tooth structure:**
				  ○ Before = 542.50 ± 81.97 mm^3
				  ○ After = 487.87 ± 74.70 mm^3
				
				<u>**Freehand group:**</u>
				
				- **Global coronal deviation:** 1.13± 0.84 mm
				- **Global apical deviation:** 4.49 ± 2.10 mm
				- **Angular deflection:** 1.75° ± 0.63°
				- **Operation time:** 8.30 ± 4.65 min
				- **Volume of tooth structure:**
				  ○ Before = 571.34 ± 132.5 mm^3
				  ○ After = 533.16± 133.12 mm^3
				
				No perforation was detected in the DNS and FH groups.
					• DNS is more accurate and efficient in removing fiber posts from root canal treated teeth than the FH technique.
					• The DNS required less operation time than the FH technique. And had significantly less volumetric loss of tooth structure than the FH technique.
					
					• DNS group had significantly less global coronal and

		A 1.1-mm wide parallel fiber post (ParaPost Fiber Lux, Coltene/Whaledent) was fitted in the canal and cut 2 mm below the access opening level. The posts were luted in the canal using RelyX Unicem (3M ESPE, St Paul, MN), and core buildup was performed using Paracore (Coltene/Whaledent) Teeth were mounted in a tissue-denuded cadaver maxilla. A total of 4 tissue-denuded cadaver maxilla models were used.	depth needed to remove the fiber post were planned. -A size #2 (1.1 mm wide) Munce bur (CJM Engineering Inc, Ojai, CA) to drill 9 mm. Then, a size #1 (0.9 mm wide) Munce bur (CJM Engineering Inc) was used to complete the drilling at 12–13 mm. New burs were used for each tooth. After system calibration and drilling trajectory was planned, drilling through the post was done under the complete guidance of the navigation of the X-guide system (X-Nav Technologies) on a slow-speed handpiece at 5000 rpm (WS-56L; W&H, Ontario, Canada). Drilling was stopped when the drill reached the end of the preplanned path indicated in the system display. **<u>FH group:</u>** - All the steps used to plan the procedure for the DNS group previously listed were virtually the same for the FH group. The drilling through the fiber post was performed FH under a DOM (Global Surgical Corporation, St Louis, MO). - The drilling was stopped when gutta-percha was visualized in the canal under the dental operating microscope (DOM).		apical deviations than the FH technique. • DNS was more accurate and efficient in removing fiber posts from endodontically treated teeth than the FH technique.

Endodontic Retreatment Using Dynamic Navigation: A Case Report **Bardales-Alcocer J. et al. (2021)** Case report (16)	This case report demonstrates the use of DNS to remove a post from under a zirconia crown for the retreatment of a failing root canal procedure.	A 30-year-old male patient reporting pain in the left maxillary lateral incisor The tooth had been endodontically treated approximately 15 years prior. Pain was evident on percussion and palpation, periapical pathology was evident radiographically, as was the presence of a fiber post.	- **Importation of the patient's CBCT data set** for planning the path through the zirconia crown and along the rectilinear path of the fiber post - **Registration** is traced for mapping the patient's jaw onto the CBCT. A tracer tool is calibrated, and the teeth with the landmarks are "painted" by the tracer tool to register the jaw on the CBCT interface. - **Calibration of the handpiece and bur tip** before initiating the procedure - High-speed handpiece and a Great White Z GWZ 801-014 diamond bur for zirconia. - When the coronal extent of the fiber was revealed, a drill tag was placed on an ultrasonic handpiece, and an ED 7 ultrasound tip was calibrated. - Residual gutta-percha was removed with #15 K-file.	Dynamic navigation was used to develop a minimally invasive access cavity preparation through a zirconia crown and to remove a fiber post from the post channel. The real-time feedback capability enabled the preservation of the root structure without weakening the walls. The system has the advantage of allowing modification of the plan during the procedure, which is impossible when using static guides. As of 18 months after the end of treatment, the patient has been completely asymptomatic, and the periapical lesion is in remission	In this case report, DNS allowed for the planning of a minimally invasive access path through a crown and the precise removal of a fiber post using real-time feedback from the instrument tip.

Real-Time Guided Endodontics with a Miniaturized Dynamic Navigation System Versus Conventional Freehand Endodontic Access Cavity Preparation:	Evaluate substance loss and the time required for access cavity preparation (ACP) using the conventional freehand method (CONV) versus a miniaturized	3 different sets of maxillary teeth (3 central incisors, 3 lateral incisors, and 3 canines) were fabricated 4 times each, resulting in a total of 12 models with a total of 72 teeth. Which were monted in anatomically correct positions.
		
		RTGE group (n = 36)
		
		CONV group (n=36)
			<u>RTGE group:</u>
			
			- Tray (DENATRAY, Mininavident AG) and marker (DENAMARK)
			- Intraoral scanning (TRIOS 3; 3Shape A/S, Copenhagen, Denmark)
			- CBCT imaging of voxel size of 125 mm, 90 kV, 6 mA, and a field of view (FOV) of 6x6cm (Accuitomo 170; Morita Manufacturing Corp, Kyoto, Japan)
				<u>Substance loss:</u>
				
				- RTGE group:
				  ○ Operator 1: 10.3 (6.4–14.2) mm^3
				  ○ Operator 2: 10.6 (6.0-15.2) mm^3
				  ○ Mean: 10.5 (7.6–13.3) mm^3
				
				- CONV group:
				  ○ Operator 1: 19.9 (13.9–25.9) mm^3
					RTGE using a miniaturized DNS leads to more accurate access cavity preparation with significantly less substance loss than CONV. Moreover, using the described experimental setup, an endodontically less experienced

Substance Loss and Procedure Time **Connert et al. (2021)** Ex vivo study (17)	dynamic navigation system of real-time guided endodontics (RTGE) in an in vitro model using 3-dimensional–printed teeth.		- DENACAM, a DNS with a stereo camera mounted to the handpiece + DENAMARK marker. - standard cylindrical diamond bur with a diameter of 1.0 mm (Intensiv SA, Montagnola, Switzerland) <u>CONV group:</u> - Contra-angle handpiece (T1 Classic S 200 L; Dentsply Sirona, Bensheim, Germany) - Standard cylindrical diamond bur with a diameter of 1.0 mm (Intensiv SA, Montagnola, Switzerland) Postoperative CBCT scans of all 12 models.	○ Operator 2: 39.4 (32.4–46.4) mm³ ○ Mean: 29.7 (24.2–35.2) mm³ <u>Procedure time:</u> - RTGE group: ○ Operator 1: 90 (62–118) s ○ Operator 2: 305 (209–402) s ○ Mean: 195 (135–254) s - CONV group: ○ Operator 1: 124 (100–150) s ○ Operator 2: 265 (242–288) s ○ Mean: 193 (164–222) s	operator accomplished minimally invasive access cavity preparations that were comparable with a more experienced operator.
Application of computer-assisted dynamic navigation in complex root canal treatments: Report of two cases of calcified canals **Machado P. et al. (2022)**	Usefulness of the computer-assisted DNS for the root canal treatment of two cases of teeth with a history of traumatic injury, extensively obliterated root canals and crown discoloration.	<u>Case 1:</u> - 37-year-old woman, evaluation and treatment of a maxillary left central incisor with yellowish and tenderness to percussion in the apical region. - Nine years previously, the patient was treated for an acute traumatic injury and subluxation of this tooth. - CBCT revealed a sharp palatal dilaceration of the root apex and a buccal canal ramification located in the apical third of the root.	- Preoperative CBCT images, operated at 90 kVp, 14 mA, 50 × 40 mm of field vision, voxel size 75 μm, 16 bits, and 15 s of exposure time and archived as DICOM and uploaded into the Navident® planning software. - The CBCT images were matched either through a Head-Tracker device secured on the patient's nasion for the treatment of the upper tooth, or a Jaw-Tracker, fixed on the crowns of neighbouring teeth with a dual-cure resin cement. - The matching was achieved by means of the trace registration protocol. The system captures a cloud of points along the path to spatially orient the tool tag,	At the 12-month recall examination, the patients continue to be asymptomatic with an improved tooth color. **Case 1:** CBCT examination disclosed a bony defect almost resolved exhibiting substantial changes in the density of the lesion with reconstruction of the buccal cortical plate in the case 1. **Case 2:** normal periapical structures (complete healing) The patients are closely monitored at 3-month intervals and will be kept under long-	The use of DNS contribute to a successful clinical outcome of the orthograde approach of teeth with PCO in need for endodontic treatment by means of a timesaving, conservative, safe and accurate approach.

Case report (18)		Case 2: - 43-year-old female patient consults for evaluation of yellowish discoloration of mandibular left central incisor - CBCT examination disclosed obliteration of the middle and cervical root canal thirds along pulp chamber calcification.	therefore mapping the patient's jaw to the CBCT scan. This tracing was finished by a full accuracy check performed by touching all surfaces of the teeth with the tip of the tracer tool. - An optical tracking tag (Drill Tag) was secured to the high-speed handpiece with an Endoguide EG4® precision micro endodontic bur (SS White®, New Jersey, USA) in place and calibrated to provide an optical triangulation tracking by the Micron Tracker stereoscopic camera. - The access cavities were prepared on the centre of the palatal surface for the maxillary left central incisor or through the incisal edge for mandibular left central incisor. - The working length, measured with an apex locator Root ZX II® (J. Morita Manufacturing Corp.®, Kyoto, Japan) and the cleaning and shaping processes were performed with a HyFlex® Controlled Memory (CM) system (Coltene-Whaledent®, OH, USA)	term review to evaluate treatment success and to check any evidence of signs and/or symptoms of inflammation.	
Guided endodontics of calcified canals: The drilling path of rotary	Evaluate the drilling path (mm) and the dentin wear (mm^3) of two	20 caries-free mandibular incisors. fixated in articulated models.	Virtual design drill path and guide construction: **CBCT scan** (Yoshida Dental Mfg. Co. LTD., Tokyo, Japan) with an endodontic acquisition	Drilling path: • Munce bur: (1.33 ± 0.10) mm • DSP bur (1.29 ± 0.11) mm	The different burs used had no influence on the drilling path accuracy during the

systems and intracanal dentin wear **Pires C et al. (2022)** Ex vivo study (19)	instruments used during guided endodontic access.	**Group (G)1:** Size 1 Munce Discovery bur (n=10) **G2:** DSP bur (n=10)	protocol of 90kV, 4 mA, 37 s, isotopic voxel of 0.10 mm and field of view of 5 × 5 mm. **Intraoral scanning** with the Trios 3 scanner (3Shape, Copenhagen, Denmark). **Virtual acess cavity and 3D printing:** Blue Sky Bio software (Blue Sky Bio, Grayslake, USA) **3D printer:** P30 (Straumann Group, Basel, Switzerland) using Sheraprint resin—Dental SG (Shera Werkstoff; Technology Gmbh & Co, KG, Lenforde, Germany). Bur: G1: **Size 1 Munce Discovery bur** (CJM Engineering, Santa Barbara, EUA), 0.8 mm in diameter, 34 mm in length and 16 mm of active part. G2: **DSP bur** (Biomedical, Campo Largo, Brazil) with 1.0mm in diameter, 25 in length and 18mm of active part. The procedures in all experimental phases were performed by a single endodontist.	Dentin wear: • Munce bur: (3.37 ± 1.57) mm^3 • DSP bur: (2.02 ± 0.98) mm^3 No difference between the burs in the analyses of the angle deviations of the virtual and the real drilling paths.	guided endodontic access. However, the diameter and the design of the bur affected the dentin wear. The Munce bur (0.8mm) removed a greater volume of the tooth structure than the DSP bur (1.0mm). There was a linear relationship between the drilling path accuracy and dentin wear.

The accuracy of using guided endodontics in access cavity preparation and the temperature changes of root surface: An in vitro study **Zhang C. et al. (2022)** (20)	Present digital design and 3D-printed guide plates to access cavity and root canal pathways shaping for isolated teeth, Evaluate their accuracy was evaluated. Compare surface temperature changes during 3D-printed guide plates guided RCT with nickel-titanium instruments and ultrasound instruments commonly used in RCT, and their safety.	Forty selected premolars. - Study model group - ET20 group - Protaper F3 group - Guided endodontics group	<u>Sample preparation:</u> **CBCT scan** (NewTom 5G, QR Srl, Verona, Italy) at 110kV, 3~9mA, a field of view of 8cm×12cm, a basic voxel size of 0.30mm <u>Virtual design drill path and guide construction:</u> **3D scan:** (TRIOS 3, 3Shape, Denmark). **Virtual bur** with 0.8mm diameter and 18mm work length (Shanghai LZQ Precision Tool, China). **3D printer** (Projet 7000MP, 3D System Int, USA) and Epoxy resin, guided metal tubes embedded in the plates have a wide inner diameter (3.5mm). **Sleeve:** guided diamond bur (1.4 mm diameter), custom guided bur (0.8 mm diameter). <u>Temperature measurement:</u> **K-type thermometer** (Center 301, type-K, tenmars, Taiwan, 0.1°C)	<u>Accuracy:</u> - 36 teeth successfully reach the working length. - Minimum angle deviation: 0.23° - Maximum angle deviation: 7.31° - Mean angle deviation: 3.62° ± 1.89° <u>Temperature:</u> - The root surface of the guided endodontics group raised 5.07 °C, which was lower than that of the F3 group (6.58°C) (P=0.046) and significantly lower than that of the ET20 group (18.17°C) (P<0.01). There were significant temperature changes between guided endodontics and ET20, guided endodontics, and F3 after 20seconds (P < 0.05).	The access cavity preparation performed with guided endodontics has feasible accuracy and low temperature rise on the root surfaces, indicating their high reliability and safety in clinical applications in complex RCT.

Treatment of Pulp Canal Obliteration Using a Dynamic Navigation System: Two Case Reports **Wu et al. (2022)** (21)	Describe in detail the use, advantages, disadvantages, and limitations of a novel dynamic navigation system in 2 cases with severely calcified canals.	Case 1: - 43-year-old man with a pustule in the mandibular anterior region - Tooth #8 (1.1) asymptomatic, with no pain on percussion or sinus tract. It did not respond to thermal and electric pulp tests. - A periapical radiograph revealed an apical radiolucency in relation to tooth #8 (1.1) with a calcified pulp chamber and narrowed root canal. - CBCT revealed a radiolucency of 12.1*7.2*11.1 mm around the apex of tooth #8, with a severely calcified pulp chamber and a narrowed root canal. - Tooth was diagnosed with asymptomatic apical periodontitis and PCO. Case 2: - 62-year-old man. - Clinical examination revealed that he had poor oral hygiene, and the mandibular anterior teeth were severely attrited. - The preoperative periapical radiograph showed a periapical radiolucency in relation to tooth #25 (4.1), and teeth #23−26 had	- U-shaped registration device with several radiopaque fiducial markers was molded to the maxillary anterior using silicone rubber. - Full-arch CBCT, (90 kVp; 3.0 mA; field of view, 11 x 8 cm; voxel size, 0.25 mm) - CBCT images exported in Digital Imaging and Communications in Medicine (DICOM) format and then imported into the DNS software (DCARER, Suzhou, China). - The reference device was fixed onto the left maxillary teeth, followed by matching of the registration device and drill with the handpiece. - Round diamond bur in a high-speed handpiece followed by the spiculate drill. - #8 K-file and the working length was determined using an electronic apex locator (Propex II; Dentsply Maillefer, Ballaigues, Switzerland) and a periapical radiograph. - #10 and #15 K-files followed by primary nickel-titanium rotary instruments (WaveOne Gold file, Dentsply Tulsa Dental Specialties and Dentsply Maillefer).	Case 1: Asymptomatic at the follow-up, and a periapical radiograph revealed a decrease in the periapical radiolucency around tooth #8 Case 2: Was advised long- term follow-up observation.	DNS is considered a promising technique due to its highly predictable outcome, lower risk of iatrogenic damage, and significantly reduced operation time.

		calcified pulp chambers and narrowed root canals. - A perforation in the neck of tooth #26 (4.2) was noted distally. - Tooth #25 was diagnosed with chronic apical periodontitis with PCO. - Tooth #26 was diagnosed with chronic pulpitis with perforation and PCO. - Teeth #23 (3.1) and #24 (3.2) were diagnosed with chronic pulpitis with PCO.			

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5. DISCUSSION:

5.1. Indication and purpose of the guided endodontics:

5.1.1. Purpose:

Although it is considered essential to the outcome of endodontic therapy, initiating endodontic access cavities is also one of the most difficult and complex steps, particularly in cases where a PCO is present. The clinical challenges of reaching into the canals and utilizing an instrument on those become more complex in posterior teeth with pulp canal calcification. A higher risk of root perforation arises from limited mouth opening, poor vision, and the posterior teeth's weaker dentin walls. The localization of calcified canals in molars is an unsafe process because of the inclination of the teeth and the existence of root curvature(4).

"Guided endodontics is recommended to overcome the problems of endodontic treatment on teeth with an unusual morphology." (19)

Recently, the field of endodontic therapy has seen the introduction of the guided endodontics procedure due to advancements in CBCT and 3D rapid prototyping manufacturing technologies. (20) The DNS has been introduced to endodontics lately, following to the same principle of guided endodontics. Endodontics has embraced DNS technology, which has been adopted in implant dentistry. This 3D real-time motion tracking system is known as DNS. It is based on overhead tracking cameras that record the operator's bur movement and the patient's jaw position. (15)
Because of its extremely predictable results, lower risk of iatrogenic injury, and drastically shortened surgery time, DNS is regarded as a promising treatment (21).

It has been shown that sinus perforations or inferior alveolar nerve injuries during drilling can be reduced by using these guided systems. (14)

5.1.2. Indications:

Root canal treatment, mainly involving calcified canals is a difficult procedure to perform since the dentist must estimate the precise location of anatomical structures and clean a complex system. Advances in digital technologies provided new tools to assist root canal treatment, such as surgical guides, 3D printing models and virtual reality simulation to improve the accuracy of clinical procedures (19)

The most frequent clinical sign of PCO found in approximately 70%–80% of teeth is tooth discoloration caused by loss of translucency due to dentin calcification within
the pulp chamber. Given that teeth most affected by PCO are in the esthetic zone, different treatments have been described for the restoration of discolored PCO teeth, including external or vital bleaching, internal and external bleaching without root canal treatment, internal bleaching with root canal treatment, and a prosthetic approach. Among these options, internal bleaching has been shown to be esthetically predictable and stable, conservative, and inexpensive. Therefore, root canal treatment is considered an indication for the treatment of discolored PCO teeth when internal bleaching is required. (12)

Another indication for root canal therapy in PCO teeth is in cases with acute symptoms or apical lesions. Although PCO is considered a sign of pulp vitality, which does not require endodontic treatment, pulp necrosis with a periapical lesion may develop unexpectedly after several years, in up to 38.2% of cases. (12)

Preparing access cavities in calcified teeth is clinically challenging. Errors in this crucial stage can have disastrous consequences, particularly in teeth like mandibular incisors that have less dentin. A failed search for calcified canals could lead to severe dentin loss, gouging, and perforation. (6)

Guided endodontics, including SNS and DNS, has been introduced for the treatment of calcified root canals. Although computer aided SNS techniques have high efficacy rates for root canal location, they are difficult to apply in cases of smaller or limited mouth openings or posterior teeth with limited access. (21)

The guided endodontics allowed access to cavity procedures with less dentin removal, in less time, compared with the conventional technique. (19)

In cases of dental development malformations, such as dens invaginatus/evaginatus, where multiple precise and conservative access cavities are required to localize individual root canals, even for performing a conservative osteotomy and root-end section in endodontic microsurgery, computer-aided dynamic navigation is particularly advantageous.(14)

5.1.3. Protocols:

Essentially, there are two types of guidance: static and dynamic. These methods require a necessitate preoperative CBCT and 3D surface scans for treatment planning. This digital approach offers a thorough knowledge of the patient's anatomy and facilitates enhanced treatment planification.

A preoperative CBCT is performed, data are stored as a DICOM file. Then these files are imported into an implant/ access planning software to map the dentition.

In both navigation techniques, the models undergo scanning using an intraoral scanner, and the surface data is then saved in the STL file format.

In the Static guidance technique, there is a utilization of a fixed surgical stent, which is made using computer-aided design/computer-assisted manufacture (CAD/CAM), based on the preoperative CBCT scan. Static surgical guides can be tooth-, mucosa-, or bone-supported. (9)

In both techniques, the two different types of datasets are superposed in an access planning software. Virtual templates, and virtual drill paths are designed by matching CBCT data and the 3D surface scan of the oral cavity.

The dynamic navigation system implies the usage of a head tracker attached to the nasion of the patient to treat involved maxillary tooth and a jaw tracker when used to treat impacted mandibular tooth. Then, an optical drilling tag is attached to a high-speed bur. A tracker camera provides a triangulation which displays in real time the position of the bur on a screen.

5.2. Advantages of the guided endodontics:

5.2.1. Accuracy:

In vitro and ex-vivo studies assessed the reliability, accuracy, and reproducibility of both guided endodontic techniques (4,6–8,20). Studies demonstrated that the operators and software for managing the design and measurements have no effect on the precision of these methods.(20)

Furthermore, various studies have confirmed the accuracy of the Guided Endodontics techniques.

Dianat et al. compared the accuracy and efficiency of the DNS versus the FH method for locating and treating calcified canals. It was demonstrated that the root canals were successfully found in 96,6% of teeth without perforation. The FH method resulted in 5 perforations. Lower angular and linear deviations, coupled with minimal reduction in dentinal thickness, demonstrated greater precision of the DNS. (6)

Buchgreiz et al. assessed the precision of guided endodontic access for pulp canal obliteration, finding that employing this method leads to a drill trajectory with accuracy reaching below a predetermined risk threshold. They set a standard (I = 0.7 mm) for the maximum permissible distance between a well-defined apical target point and the midpoint of the drill trajectory within dentin. The results of their study revealed a notably smaller average distance of 0.46 mm ($P < 0.001$, 95% CI; 0.31-0.49), indicating enhanced accuracy. (7)

Moreover, *Janabi et al.* investigated the accuracy and efficiency of the DNS to remove fiber posts in previously treated root canals compared to the FH technique. It was proved that the DNS is more accurate and efficient, which was demonstrated with a limited coronal and apical deviation in the DNS.(15)

On top of that, *Jain et al.* presented the accuracy of the DNS technique on maxillary and mandibular tooth. It was found that the mean 2D horizontal deviation of 0.9 mm, a mean 3D deviation of 1.3 mm and a mean 3D angle deviation of 1,7° from the canal orifice with high-speed drills, which could be considered relatively safe for deep endodontic access cavity preparations (11)

Similarly, the in vitro study of *Zhang et al.* revealed that the deviation angles and directions were negligeable, is consistent with other previous studies indicating that the high precision of the guided endodontics with a negligeable effect of operators or software. (20)
While *Zubizarreta et al.* analyzed the performance of DNS and SNS compared to FH techniques. The results showed that the DNS group was more accurate than the static and FH methods with less angular and horizontal deviations.(14)

5.2.2.Conservation of the teeth and periodontium:

CBCT imaging is a key element in the guided endodontic techniques, it allows a 3D representation of the obliterated root canals which enables the clinicians to locate them and assess the degree of PCO. It prevents extensive canal preparation which could weaken the tooth structure. (12)

Zhang et al. in their study showed that the root surface of the guided endodontics group reached 5.07 °C, which was lower than that of the Protaper F3 group (6.58°C) (P=0.046) and significantly lower than that of the ET20 group (18.17°C) (P<0.01). This indicates that the guided endodontics techniques are safe because it was below the safe threshold indicated in the literature. (20)

Moreover, *Pires et al.* evaluated the dentin wear of two instruments used during endodontic access. Despite the inferior diameter of the Munce Bur (0,8 mm), it wore a larger amount of dental structure compared with the DSP bur (1,0 mm). As a matter of fact, the Munce bur has a smaller active part than the other bur, which implies that the sleeves used are not suitable. And a positive linear correlation was found between the drilling path and dentin wear ($R^2 = 0,859$).(19)

Also, *Jain et al.* compared the substance loss between FH and DNS. They found that DNS resulted in significantly less teeth substance loss 27,2 mm^2 versus 40,7 mm^2 for the FH technique. (11)

Similarly, *Connert et al.* estimated the substance loss between the DNS and the conventional FH technique. The results showed that the DNS preserves more tooth structure than the FH technique. Which makes that these root canal treated teeth have an increased fracture resistance. (17)

5.2.3. Time saving and experience of the operator:

Connert et al. evaluated the procedure time between the DNS and the conventional FH technique. It was found that there was no significant time difference between each technique. They also discussed in their study that an endotically less experienced operator accomplished ACP that were comparable to treatment performed by a more experienced operator. (17)

Also, *Jain et al.* noticed that with the DNS compared with the FH technique, the less skilled operators have a rapid learning curve, which makes the DNS a possible educational tool. (11)

5.2.4. Comparison of conventional and guided methods:

Even though patients are exposed to radiation during CBCT scans, the overall exposure is lower compared to traditional treatments for calcified teeth. This is primarily because there's no need for multiple radiographs to verify the position of the instrument used to locate the canal like in the conventional FH technique. (4)

The teaching objective derived from the study of *Zubizarreta et al.* is that manually performed (FH) endodontic access cavities result in decreased accuracy compared with computer-aided static and dynamic navigation systems.(14)

5.3. Disadvantages and limitations of the guided endodontics:

5.3.1. Limitations of the Static Navigation system:

The SNS approach has several limitations. Each stage in the digital workflow has the potential to introduce inaccuracies. Moreover, it involves creating a 3D-printed endodontic guide, which adds complexity to the process. Furthermore, this guide can be challenging to utilize in posterior regions with restricted interocclusal or interdental spaces. Another significant drawback is the absence of real-time 3D visualization during drilling through the post, which prevents intraoperative adjustments to the predetermined drill path.(15)

Furthermore, planning and manufacturing the template are time-consuming.

This technique may not be suitable for all posterior teeth due to the need for extra working space to accommodate the 3D guide and the bur. Additionally, the straight shape and rigidity of the bur pose an anatomical constraint in curved canals. (12)

Even though it's uncommon for a root canal to be calcified all the way to its apical third, as demonstrated in the study of *Buchgreiz et al.*, extending the drill path apically without considering curvature could result in root damage. Therefore, it's important to emphasize that the presented technique may have anatomical constraints, not only in severely curved roots but also in cases involving radicular grooves, oval roots, or isthmuses. (8)

The accuracy of the drilling path and the extent of dentin wear can be influenced by various factors, including the reproducibility of different digital models, the quality and precision of three-dimensional imaging and printing, as well as the planning workflows. Additionally, the software and type of material used in printing the guides can also impact these aspects. (19)

Zhang et al. in their laboratory study found a higher deviation of the angle of the bur. It was specified that there was a difference of diameter of 0,5 mm between the bur and the metal sleeve, which created a slight vibration. It led to the deviation od the planned path. They advised that reducing the tolerance between the bur and the slightly oversized sleeve could enhance the accuracy of cavity preparation. (20)

Moreover, SNS presents other limitations such as the restricted visual field within the endodontic access cavity, despite using transparent plastic, the necessity for matching between DICOM files and intraoral scans for digital planning and subsequent impression of the template which could take up to 2 hours. (18)

5.3.2. Limitations of the Dynamic Navigation method:

Learning to operate the DNS involves a learning curve for the operator. He needs to maintain the correct position and angulation of the handpiece while looking at a display screen. Motor control, eye-hand coordination, manual dexterity, system knowledge, and continued practice are necessary to attain proficiency. It is advised that 20 trials are performed with the DNS before performing on actual patients. (6)

As stated in *Wu et al.'s* paper, DNS could be affected by various factors, which are the image quality of the CBCT, patients' movement during the CBCT or during the DNS procedure. The stability of the registration device, the reference device, and the tooth are crucial factors for ensuring procedural accuracy. (21)

Besides, *Janabi et al.* presented another constraint of the DNS technique, it is the necessity to leave an X-clip with three radiopaque fiducials in place on the opposing side from the procedure in the opposing arch. Patients who are either edentulous in that region or have severe tooth mobility may not be suitable candidates for this procedure. (15)

6. CONCLUSION :

The purpose of this present study was to compare the differences between SNS and DNS concerning accuracy and conservation of teeth structure. The null hypothesis" there is no difference between SNS and DNS regarding the accuracy and conservation of tooth structure and therefore both techniques have the same advantages and limitations" is rejected.

As a matter of fact, this study indicates that DNS is superior to the SNS technique in terms of tissue conservation and accuracy.

These techniques have shown an acceptable performance in situations such as severe PCO, fiber post removal, and dens invaginatus.

In spite of elevated costs for the patients, difficult to access teeth and increased radiation exposure, these methods are promising for the future of endodontics.

Conversely, it is important that more in-vivo studies are conducted to enhance these computer-assisted techniques.

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