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MINIMALLY INVASIVE ENDODONTICS: PRESERVING TOOTH STRUCTURE IN MODERN PRACTICE

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ABSTRACT

Introduction: Minimally invasive endodontics emphasize preserving enamel and dentin during treatment to maintain structural integrity and enhance fracture resistance, since lost dentin cannot be biologically replaced. However, fundamental principles of endodontic success—adequate disinfection, proper canal shaping, and three-dimensional obturation—must always be respected. **Objective:** This paper aims to highlight the advantages of conservative approaches in endodontic procedures, particularly in access cavity preparation and canal shaping, while discussing the potential risks and limitations associated with excessively restrictive techniques. **Materials and Methods:** A literature review was conducted using PubMed, Google Scholar, ScienceDirect, and Wiley Online Library databases. Human studies, clinical trials, in vitro studies, case reports, and review articles were included. Of 330 initially identified publications, 32 met the inclusion criteria and were analyzed. **Results:** Five minimally invasive access cavity designs were identified: Conservative Access Cavity (CAC), Ninja Access Cavity (CAN), Truss Access Cavity (TrussAC), Caries-driven Access Cavity (CariesAC), and Restorative-driven Access Cavity (RestoAC). These approaches promote greater preservation of healthy dental tissues and may improve mechanical resistance. Nevertheless, maintaining a balance between tissue conservation and effective cleaning, shaping, and obturation of the root canal system remains essential. **Discussion:** Preservation of peri-cervical dentin and the soffit plays a crucial role in reinforcing tooth resistance. Advances such as magnification, ultrasonic inserts, cone beam computed tomography, and guided endodontics enhance procedural precision. However, excessive conservation may increase risks, including inadequate debridement, canal transportation, file separation, and other procedural errors. **Conclusion:** Minimally invasive endodontics must prioritize biological objectives while preserving tooth structure, ensuring that conservation does not compromise treatment effectiveness.

KEYWORDS: Minimally invasive endodontics, conservative access cavity, dentin preservation, root canal shaping, treatment outcomes.

INTRODUCTION

In recent years, minimally invasive treatments have been increasingly adopted across all fields of medicine, driven by advances in microsystem engineering, nanotechnology, laser therapy, and high-resolution imaging tools for diagnosis and surgical guidance. Dentistry had naturally followed this trend, focusing on new ways to treat dental decays while preserving as healthy teeth as possible. The concept of Minimally Invasive Endodontics (MIE) was first introduced in 2009, distinguishing itself from conventional approaches by emphasizing the preservation of tooth structure while still achieving the core biological goals of endodontic therapy (1). In 2010, Clark and Khademi made a significant contribution by advocating for maximum dentin preservation during access cavity preparation and canal shaping, based on two key arguments:

– Reducing dentin volume compromised the tooth’s long-term resistance to masticatory forces (3),

– And no artificial material could truly replicate lost dentin tissue (2).

Like in other medical fields, this approach relied on advanced training and technologies such as cone-beam computed tomography (CBCT), magnification, high-intensity lighting, ultrasonic tips, irrigation systems, and heat-treated NiTi instruments. From this foundation emerged the controversial idea that “the more dentin is preserved, the better the outcome,” leading some practitioners to adopt extremely conservative strategies known as “ninja” or “truss” accesses (4). Minimally invasive strategies are now influencing every phase of endodontic treatment from access cavity design and canal instrumentation to apical surgery. However, a thorough understanding of anatomical structures and their variations remained essential at each stage (5). Despite growing interest in these techniques, especially on social media, scientific evidence supporting the integration of such conservative cavity designs into routine clinical practice or dental education remained limited (6). This review aimed to explore current literature to highlight the benefits of a more conservative approach to dentin preservation during access and canal shaping, while also addressing the risks and limitations of uncritical application of MIE principles.

MATERIALS ET METHODS

1. Study Type and Research Question: The objective of this work was to address the following research question through a literature review: "What were the benefits and limitations of a non-invasive approach to dental structures during the preparation of the access cavity and canal shaping?"
2. Literature Search Strategy: Data collection for this review was primarily conducted using the "PubMed" database. Additional sources such as "Science Direct," "Google Scholar," and "Wiley Online Library" were consulted to enhance the search. The bibliographies of selected articles also led to further relevant studies. The following English keywords were used:

- Tissue economy (Mesh terms)
- Minimally invasive endodontics (Mesh terms)
- Access cavity preparation (Mesh terms)
- Endodontics (Mesh terms)
- Conservative endodontic cavities (Mesh terms)
- Contracted endodontic cavities (Mesh terms)
- Effect of endodontic access cavities (Mesh terms)
- Impact of contracted endodontic cavities (Mesh terms)

Boolean equations used in the search were:

- Theory AND practice of minimally invasive endodontics.
- Traditional AND minimally invasive access cavities in endodontics.

These terms were applied to each database separately and in combination to identify articles for inclusion.

3. To ensure relevance and quality, the included studies were selected based on predefined inclusion and exclusion criteria:

Inclusion Criteria:

- Articles addressing the objectives of the literature review.
- Studies involving human natural teeth.
- Meta-analyses, systematic reviews, and literature reviews on the topic.

- Randomized controlled clinical trials.
- In vitro experimental studies.
- Case reports.
- Published between 1996 and 2021.

Exclusion Criteria:

- Articles with irrelevant titles or abstracts.
- Non-randomized trials.
- Expert opinions.
- Articles written in languages other than French or English.

4. Selection Strategy

Article selection was done independently by the doctoral candidate and the thesis supervisor. The first screening was based on titles identified relevant articles. If the title was pertinent, the abstract was reviewed. Articles providing useful results were then fully read. Irrelevant articles or those failing to meet inclusion criteria were excluded. The final selected publications formed the basis for analysis in the Results and Discussion section.

5. Data Extraction

The review was structured using the PICO criteria:

- P: Participants/Problem: Endodontically treated teeth.
- I: Intervention: Minimally invasive endodontic treatment.
- C: Comparison: Minimally invasive access cavities vs. traditional access cavities.
- O: Outcomes: More effective and successful root canal treatment by preserving tooth structure.

6. Synthesis and Analysis of Literature

Articles were included if they clearly described minimally invasive endodontic treatment and provided details on the clinical protocol, benefits, and risks. The evaluation of minimally invasive treatments was based on statistical, mechanical, and biological tests, allowing assessment of criteria such as fracture resistance, canal disinfection, and endodontic obturation.

RESULTS

An initial total of 330 articles were identified through the literature search. After screening titles and abstracts for relevance, 76 articles were selected for further evaluation. Following the removal of duplicates and full-text assessment, 40 articles remained. Ultimately, 33 studies met the predefined inclusion criteria and were included in the final review. The selection process was illustrated in a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram **(Fig. 1)**. The included studies were summarized in **Tables I and II.**

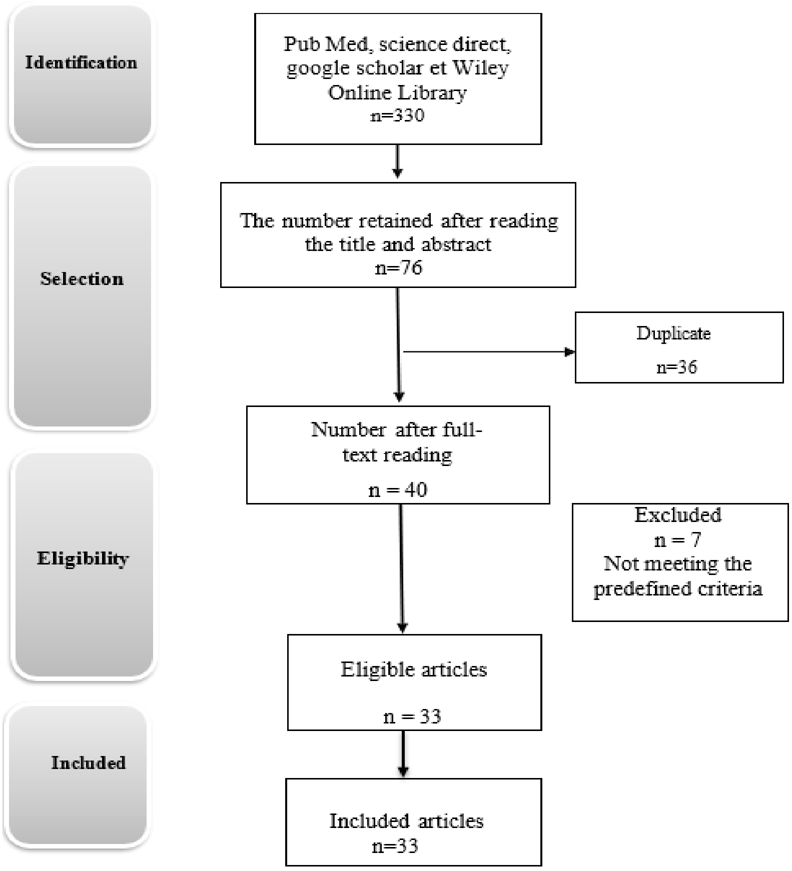

Figure 1: Diagram of the Article Selection and Identification Process (Flowchart)

Table I: Descriptive Table of the Studies Included in the Literature Review

Article		**Results**
Autor/Année	**Article Title**	
Kimura Y & coll 2000 (25)	Lasers in endodontics	Laser-activated sodium hypochlorite irrigation has been proposed in minimally invasive endodontics as an alternative to the conventional disinfection approach, aiming to enhance the disinfection efficacy of NaOCl in endodontic treatment.
Patel S & coll 2007 (9)	The potential applications of cone beam computed tomography in the management of endodontic problems.	These minimally invasive cavities are prepared after a thorough CBCT analysis, which, using a low radiation dose, enables the detection

		of all canal entrances of the tooth to be treated.
Clark D & coll 2010 (2)	Modern molar endodontic access and directed dentin conservation	The targeted preservation of dentin and enamel is the most proven method for reinforcing an endodontically treated molar.
Sebastian & coll 2014 (5)	« Minimally invasive endodontics »	Minimally invasive strategies will likely replace more invasive methods at every stage of root canal treatment.
Boveda C & coll 2015 (7)	Contracted endodontic cavities: the foundation for less invasive alternatives in the management of apical periodontitis.	The primary difference between CAC and TAC is in their area and volume, with CAC being smaller.
Didier Nunzi 2018 (28)	Utilisation du laser en endodontie.	Laser diode-activated NaOCl irrigation can also be used in minimally invasive endodontics, as it provides better disinfection than using the laser diode alone.
E. J. N. L. Silva & coll 2020 (6)	Current status on minimal access cavity preparations: a critical analysis and a proposal for a universal nomenclature.	Five types of minimally invasive cavities have been reported: • CAC: Conservative Access Cavity • ACN: Ultra-conservative Access Cavity or "Ninja" • TrussAC: Truss Access Cavity • CariesAC: Caries-induced Access Cavity • RestoAC: Restoration-focused Access Cavity
Lucas Massat 2020 (8)	Cavités d’accès endodontiques à minima : Influences sur la thérapeutique endodontique et sur la dent restaurée.	Plotino et al., Saygily et al. established the protocol for performing CAC and ACN on premolars and molars while preserving the soffit and peri-cervical dentin as much as possible. False pathways and canal deviation are limitations of this minimally invasive approach.
Eve laurent 2020 (1)	Endodontie la cavité d’accès à minima	Periapical radiographs are key in minimally invasive endodontics. Ultrasonic inserts ensure precise dentin removal, while miniaturized finishing burs provide ergonomic, less

		destructive access. However, canal omission can occur with this approach.
E.J.N.L.Silva & coll 2021(4)	Minimally invasive access cavities: does size really matter? »	This minimally invasive approach makes endodontic treatment more complex. Difficulties in locating canal orifices, the quality of disinfection, canal obturation procedures, iatrogenic errors, and tooth discoloration have been reported as possible consequences of these minimal preparations.

Table II: Descriptive table of the in vitro studies selected according to the PICO criteria.

Article	P	I	C	O
Pressure waves in root canals are induced by Nd:YAG laser. Levy G et coll, 1996 (26)	The root canals of 14 single-rooted teeth were conventionally prepared and filled with water.	In 12 teeth, a pulsed Nd:YAG laser was activated within the canal using optical fibers of varying diameters and power settings. In the remaining two teeth, either a sonic or ultrasonic file was activated. Pressure waves induced within the canals were detected using a piezoelectric transducer.	Nd:YAG laser irradiation compared to freely vibrating sonic and ultrasonic endodontic instruments.	Nd:YAG laser irradiation induced pressure waves with characteristics distinct from those generated by freely vibrating sonic and ultrasonic endodontic instruments when applied to water-filled root canals.
«A framework for the application of three-dimensiona reconstruction and measurement for endodontic research» Gao Y et coll 2009 (18)	A maxillary first molar was scanned before and after preparation with ProTaper using computed tomography.	Using a custom application framework based on MeVisLab, the internal and external anatomy was reconstructed. Additionally, root canal and	-----	Three-dimensional finite element analysis (FEA) allows for the determination of stress distribution within a structure subjected to force, using computer-generated models based on computed tomography data. Its objective is to assess the impact of

		root dentin dimensions were quantified, and the effects of canal preparation were evaluated. Finally, virtual preparation with risk analysis was performed to simulate the removal of a fractured instrument.		computer-aided minimally invasive techniques (CAMI) on the fracture resistance of teeth.
Effect of root canal curvature on the failure incidence of ProFile rotary Ni-Ti endodontic instruments. Kosti E et coll 2011 (32)	Three hundred mesial root canals of mandibular molars.	These canals were instrumented using the ProFile system with a crown-down technique up to a size 25, 0.06 taper. Root canals were classified based on curvature angle and radius into three groups: straight (Group A: 0 ± 10°, radius 0 mm), moderately curved (Group B: 30 ± 10°, radius 2 ± 1 mm), and severely curved (Group C: 60 ± 10°, radius 2 ± 1 mm).	-----	Regardless of instrument size, fractures and overall instrument failures were significantly more frequent ($P < 0.05$) in Group C. The sharp curvature of the root canal had a negative impact on the failure rate of Ni–Ti ProFile rotary instruments. Fractographic analysis confirmed that failure of the Ni–Ti files was caused by a single overload event during chemomechanical preparation.
Evaluation of the bactericidal effect of Nd:YAG, Er:YAG, Er, Cr:YSGG laser radiation, and antimicrobial	Two hundred twenty infected root canals from extracted human teeth.	These canals were contaminated with *Enterococcus faecalis* for 4 weeks and randomly	Evaluate the bactericidal effect of laser irradiation and antimicrobial photodynamic therapy in these experimentally	All tested laser irradiation protocols, particularly Er:YAG/NaClO/NS/DW, demonstrated an effective bactericidal effect in experimentally infected canals. Er:YAG/NaClO/NS/DW

photodynamic therapy (aPDT) in experimentally infected root canals. Cheng X et coll 2012 (27)		divided into five experimental groups. Endodontic treatment was performed in these groups using either laser or sodium hypochlorite.	infected canals compared to standard endodontic treatment with 5.25% sodium hypochlorite.	appears to be an ideal protocol for root canal disinfection during endodontic treatment.
«Impacts of Conservative Endodontic Cavity on Root Canal Instrumentation Efficacy and Resistance to Fracture Assessed in Incisors, Premolars, and Molars» R.Krishan et coll 2014 (16)	-Extracted intact maxillary incisors, mandibular premolars, and molars. -In total, there were 60 instrumented teeth and 30 intact teeth.	Micro-CT imaging was taken for these teeth, which were then prepared with either continuous or adaptive techniques (CAC or CAT). The canals were prepared using WaveOne instruments (Dentsply Maillefer, Ballaigues, Switzerland) with 1.25% sodium hypochlorite, and post-treatment micro-CT images were obtained. These teeth were loaded until fracture in the Instron universal testing machine.	The comparison of continuous adaptive techniques (CAC) versus controlled adaptive techniques (CAT) regarding root canal instrumentation and fracture resistance.	CAC was associated with the risk of compromised root canal instrumentation only in the distal canals of molars, but it preserved coronal dentin in all three types of teeth and provided an increased fracture resistance advantage in mandibular molars and premolars.
Finite element analysis: a boon for dentistry Trivedi S 2014 (19)	------	This is a computerized in vitro study in which the clinical conditions may not be fully	------	Finite Element Analysis (FEA) is an emerging and important research tool for biomechanical analyses in biological research. It is now widely accepted as an excellent

		replicated.		non-invasive tool for studying biomechanics and the influence of mechanical forces on biological systems.
«Microinvasive endodontic access» O.A.Solovyova et coll 2015 (11)	Canines, premolars, and molars.	Cone beam computed tomography (CBCT) is used to study the structure and location of the minimally invasive access cavities and root canals in these teeth.	------	The proposed method allowed for the prevention of complications and errors during endodontic treatment, as well as the preservation of dental hard tissues during the creation of the access cavity and the identification of canal orifices.
Effect of instrument design and access outlines on the removal of root canal obturation materials in oval-shaped canals. Niemi TK et coll 2016 (30)	Mandibular premolars	These teeth were endodontically treated and obturated with warm lateral condensation of gutta-percha. Retreatment was performed using TRUShape (TS) instruments and ProFile Vortex Blue (VB) instruments.	Compare the effectiveness of TRUShape (TS) instruments with ProFile Vortex Blue (VB) instruments in removing filling materials during root canal retreatment of single-rooted mandibular premolars accessed through two access cavities.	Neither of the two retreatment protocols was able to completely remove all filling material from the root canal surface of mandibular premolars. However, with the CAC access design, the use of TS instruments removed more filling material in single-rooted oval canals.
«Microguided Endodontics: Accuracy of a miniaturized technique for apically extended access cavity preparation in anterior Teeth» T. Connert et coll 2017 (12)	Sixty healthy mandibular anterior teeth were used in 10 mandibular models	This technique is designed to treat teeth with pulp canal calcifications and narrow roots by using a printed template that guides a drill to the calcified root canal.	------	Guided endodontics provides a precise, rapid technique for treating mandibular anterior teeth with pulp canal calcifications by performing a minimally invasive access cavity preparation and canal localization.
Influence of	Thirty	These teeth	Traditional	In the palatal roots of

access cavity design on root canal detection, instrumentation efficacy, and fracture resistance assessed in maxillary molars. Rover G et coll 2017 (33)	extracted intact maxillary first molars were scanned using micro-CT imaging.	were endodontically treated using CAT (controlled adaptive technique) and CAC (continuous adaptive technique). Mandibular premolars.	endodontic cavities (CAT) were used as a reference for comparison.	maxillary first molars, the deviation of the main canal axis was significantly greater at 7 mm from the apical tip with CAC. These CAC did not increase the fracture resistance of the teeth.
Microendodontie guidée : Etude de faisabilité montrant l'économie tissulaire potentielle sur les cavités d'accès des incisives calcifiées. Roch Veysseyre 2018 (15)	Calcified incisors.	A dental arch simulator is created by incorporating teeth with calcified pulps. Endodontic planning, similar to implant planning, is performed using a guide. Guided trepanations are then carried out in this clinical simulator. Post-operative control radiographs are taken.	------	Guided microendodontics using a clinical simulator allowed for minimal access cavity preparation on intact incisors through the use of an endodontic trepanation guide.
«A New Approach for Minimally Invasive Access to Severely Calcified Anterior Teeth Using the Guided Endodontics Technique» S.T.O. Lara-Mendes et coll 2018 (14)	Maxillary anterior teeth with severe canal calcification.	Endodontic treatment is performed using a new minimally invasive approach that does not damage the teeth at the incisal edge, utilizing cone beam computed tomography (CBCT) imaging and	------	Guided endodontic therapy optimized the treatment, providing conservative access without damaging the incisal edge in a safe and predictable manner, despite the presence of a severely calcified root canal.

		three-dimensional guides.		
«Microguided Endodontics: a method to achieve minimally invasive access cavity preparation and root canal location in mandibular incisors using a novel computer-guided technique» T. Connert et coll 2018 (13)	Mandibular incisors with canal calcification and apical periodontitis.	In this technique, a 3D-printed template guides a custom drill to the root canal orifice. After negotiating the root canals, conventional root canal treatment was performed. This study demonstrates that minimally invasive access cavities, extended apically, are achievable in mandibular incisors using this technique.	-------	The "microguided endodontics" technique is a safe and minimally invasive method for locating the root canal and preventing technical failures in anterior teeth with pulp canal calcification.
«Stress distribution in a tooth treated with minimally invasive access compared to a tooth treated with traditional access: a finite element analysis study» Chad Allen et coll 2018 (17)	Four finite element analysis models of an extracted mandibular first molar was constructed.	An intact model served as the control, while the other three models were prepared with either a CAMI or traditional straight-line technique, followed by the application of an occlusal load of 100 N. The Von Mises stresses in the teeth were then calculated and analyzed.	Compare the stress distributions in teeth treated with minimally invasive access designs to those treated with traditional straight-line access, and their relationship with the final restoration.	A traditional endodontic access cavity may make a tooth more susceptible to fracture compared to a minimally invasive design.
«Impact of Access Cavity Design and Root Canal Taper on	Maxillary molars.	For the evaluation of taper, maxillary molars were	CAC compared to TCA in terms of fracture resistance.	Increasing the taper of the root canal preparation may reduce fracture resistance. CAC

Fracture Resistance of Endodontically Treated Teeth: An Ex Vivo Investigation» M, Sabeti et coll 2018 (21)		randomly assigned to one of three groups: a taper of 0.04, 0.06, or 0.08. These molars were prepared with either CAT or CAC. Fracture resistance was tested using a universal testing machine.		compared to TCA had no significant impact; it did not increase the fracture resistance of maxillary molars.
«The Effect of Endodontic Access Cavities on Fracture Resistance of First Maxillary Molar Using the Extended Finite Element Method. Y. Zhang et coll 2019 (20)	Maxillary first molars.	Based on micro-CT data, maxillary first molars treated endodontically with CAT, CAC, and CAM were analyzed. Four static loads (800 N in total) were applied vertically at the contact points. The finite element method was used to simulate the initiation and propagation of cracks in the enamel and dentin.	Fracture resistance of a tooth treated endodontically with three access cavities: TCA, CAC, and MCA.	In the cervical region, areas of higher stress concentration were found in the modified endodontic cavity and the traditional endodontic cavity compared to the natural tooth and the conservative endodontic cavity.
Effects of preparation with the Self AdjustingFile, TRUShape and XP-endo Shaper systems, and a supplementary step with XP-endo Finisher R on filling material removal during retreatment of	Mandibular molars.	Mandibular molars were instrumented, filled, and subjected to retreatment using three instrumentation systems: the self-adjusting file (SAF), TRUShape, or XP-endo Shaper.	Compare the effects of three instrumentation systems on the removal of filling material during root canal retreatment of mandibular molars.	The tested systems were equally effective in removing the filling material mass from the apical 5 mm of molar canals. The additional step with the XP-endo Finisher R improved the removal of the filling material. The XP-endo Shaper is therefore indicated for minimally invasive canal preparation as it enhances shaping and

mandibular molar canals. Machado AG et coll 2019 (24)				disinfection while preserving the maximum amount of dental structure.
Influence of minimally invasive endodontic access cavities on root canal shaping and filling ability, pulp chamber cleaning and fracture resistance of extracted human mandibular incisors. Rover G et coll 2020 (22)	Extracted human mandibular incisors.	The teeth were endodontically treated with CAT or CAMI. After the root canal obturation and cavity restoration procedures, the samples were subjected to a fracture resistance test.	Compare the difference between TAC and CAMI techniques regarding canal shaping, root canal obturation capability, cleaning of the pulp chamber, and fracture resistance.	The location and design of the endodontic access cavity had no impact on root canal preparation or fracture resistance of the extracted mandibular incisors, regardless of the instrument used. Minimally invasive access cavities were associated with significantly more voids in the root canal obturations.
Impact of contracted endodontic cavities on root canal disinfection and shaping. Vieira GCS et coll 2020 (23)	Mandibular incisors.	Conservative and conventional access cavities were prepared, and the canals were contaminated with a pure culture of *Enterococcus faecalis* for 30 days. Root canal preparation in both groups was performed using the XP-endo Shaper instrument and irrigation with 2.5% sodium hypochlorite	This study compared the disinfection and canal shaping of teeth with contracted access cavities versus teeth with conventional access cavities.	The results showed that although canal shaping using an adjustable instrument was similar between the groups, disinfection was significantly compromised after the root canal preparation in teeth with contracted endodontic cavities.
A laboratory study of the impact of ultraconservative access cavities and minimal root	Extracted intact mandibular molars.	The teeth were endodontically treated with CAT or CAMI. The root canals were obturated, followed by	Compared to CAC, TAC showed no advantage regarding canal shaping and fracture	The ultra-conservative endodontic access cavities offered no benefit over traditional endodontic access cavities in shaping the canals or in fracture resistance of mandibular

canal tapers on the ability to shape canals in extracted mandibular molars and their fracture resistance C.M.Augusto et coll 2020 (31)		restoration of the teeth before they were subjected to fracture resistance tests.	resistance.	molars. No significant difference was observed in canal transportation.
«Impacts of contracted endodontic cavities compared to traditional endodontic cavities in premolars. J, Xia et coll 2020 (29)	Forty intact extracted human first premolars, both single-rooted and double-rooted.	CAT and CAC were prepared. The CAC was prepared using a 3D-printed template, and the canals were shaped with a 0.04 tapered M-Two rotary instrument. The cavities were restored with resin. The teeth were then subjected to loading to induce fracture in an Instron universal testing machine after a fatigue phase.	Compare the percentage of dentin removed, the effectiveness of instrumentation, root canal obturation, and fracture load between contracted endodontic cavities and traditional endodontic cavities during root canal treatment of premolars.	The results of this study suggest that the CAC did not improve the fracture resistance of premolars treated endodontically. The effectiveness of instrumentation and the percentage of obturation material did not differ significantly between the CAC and the CAT in premolars.
Influence of contracted endodontic access on root canal geometry. Alovisi M et coll 2021 (3)	Thirty extracted human mandibular molars	These molars were prepared with either TAC or CAC. Each group was shaped using ProGlider and WaveOne Gold. Irrigation was performed with 10% EDTA and 5% sodium hypochlorite.	Influence of contracted endodontic access on the root canal geometry compared to traditional access.	TAC showed greater preservation of the original root canal anatomy with less apical transportation compared to CAC, possibly due to the absence of coronal interference.
La préparation canalaire minimalement invasive : Etude	------	Ultrasonic tips such as CAP1, CAP2, and CAP3 were	------	These ultrasonic tips and custom guides have enhanced our therapeutic approaches by making the

in vitro de trois limes de mise en forme endodontique. Romeo Berut 2021 (10)		used to prepare minimally invasive access cavities. Diamond-coated steel tips like ET18B or ETBD were employed for locating calcified canals. In addition to ultrasonic tips, some practitioners also use custom guides during minimally invasive endodontic treatment.		canal entries visible and ensuring that minimally invasive preparations are safer and more reproducible.

DISCUSSION

METHODOLOGY DISCUSSION:

- **In vitro Comparative Studies**: As these studies were not in vivo, it was relied on comparative studies conducted on extracted human teeth or teeth in situ.
- **Randomized Controlled Trials (RCTs)**: RCTs were commonly used to test the effectiveness of various therapeutic approaches in patient populations. They also collected data on the side effects of these treatments.
- **Simulator Studies**: These simulators consisted of plaster casts of maxillary or mandibular dental arches with extracted human teeth. Ex vivo trials were conducted on these teeth to evaluate the risk-benefit balance of a therapeutic approach before its application in patients. This setup allowed for satisfactory results in CBCT exams, enabling the clear delineation of dental tissues from plaster, which closely resembled bone tissue. The goal was to approximate an in vivo CBCT.

The limitations of our study are outlined below:

- **Language Restriction**: Only articles published in English or French were selected.
- **Variability in Evaluation Parameters and Tools**: Different studies used varying evaluation methods, including micro-CT, digital radiography, or sectioning, which are techniques that may lack reliability.

Thus, further advancements and new studies were needed to allow for a comparison between minimally invasive access cavities (MIAC) and traditional access cavities (TAC) in an in vivo scenario.

DISCUSSION OF RESULTS:

- TYPES OF MINIMALLY INVASIVE ACCESS CAVITIES: Modern dentistry favored tissue preservation, influencing the evolution of access cavity designs, primarily differing in size and invasiveness (6).

Traditional Access Cavity (TAC): Standard geometric cavity allowed straight-line access to the apical third. Facilitated instrumentation but removed significant healthy tissue, compromising biomechanical integrity (1). In posteriors, the pulp chamber roof was fully removed with divergent axial walls; in anteriors, the cavity often extended to the incisal edge.

Conservative Access Cavity (CAC) / with Divergent Walls (ConsAC.DW): In posteriors, initiated at the central fossa with converging or diverging walls while preserving the pulp chamber roof (Clark & Khademi, 2010). In anteriors, a smaller, triangular/oval cavity was created near the incisal edge to preserve pulp horns and peri-cervical dentin. **Yuan et al.** reported TAC average dimensions at **13.7 mm^2 / 109.3 mm^3**, vs. **3.2 mm^2 / 43.7 mm^3** for CACs (5). The **“soffit”** (Clark et al., 2013), i.e., the pulp horn support, and **peri-cervical dentin** (4 mm above to 6 mm below the bone crest), were preserved for long-term stability and ferrule effect (3)

Ultra-Conservative Access / Ninja Cavity (CAN): Created with minimal extension; sometimes as small perforations above canal orifices "Orifice-Directed Dentin Conservation Access Cavities." Planned with **CBCT**, which helped project canal entries perpendicularly on the occlusal surface (Patel et al., 2007) (9). In anteriors with lingual wear, access might be made at the **incisal edge** (UltraAC.Inc). The trade-off was reduced visibility and higher technique sensitivity (8, 9).

Truss Access Cavity (TrussAC): In multi-rooted teeth, two or more small cavities were prepared while preserving the dentin bridge between them for example, in mandibular molars to access mesial and distal canals (6).

Carious Access Cavity (CariesAC): Access was obtained through the removal of carious tissue only, preserving unaffected dentin. Useful for infected dentin removal but technique-sensitive and not suited to all cases (6).

Restoration-Based Access Cavity (RestoAC): Access through partial or complete removal of existing restorations in non-carious teeth, preserving as much tooth structure as possible (6).

-MINIMALLY INVASIVE ENDODONTICS: MATERIALS AND PROTOCOL: Minimally invasive access cavities demand high operator skill, optical magnification, and conservative instrumentation. Access is initiated with small-diameter diamond burs, refined using ultrasonic tips and minimally invasive burs rather than aggressive conventional instruments. Microscopes and loupes (Galilean and Keplerian) are essential for precision; microscopes improve accuracy in micro-access preparation and ergonomics, reducing operator fatigue (1,10). Galilean loupes use converging/diverging lenses, while Keplerian loupes use two converging lenses, enabling higher magnification and real image formation, often with coaxial lighting to minimize shadows (10). Periapical radiography remains the reference imaging modality; one or two preoperative radiographs are usually sufficient, while CBCT provides valuable 3D assessment in complex cases (1). Ultrasonic inserts (Start X, Dentsply; CAP, Actéon Satelec) allow controlled dentin removal under direct vision, limiting occlusal extension (1). CAP1 and Endo Z burs enable safe access without pulpal floor damage; CAP2 facilitates localization of complex or calcified canals (e.g., MV2) and dentin spur removal, while CAP3 aids pulpolith removal. Diamond-coated inserts (ET18B, ETBD) further assist in managing calcified canals (10). Finishing and refinement rely on CK burs (SS White), designed for conservative coronal access and canal relocation using FG diamond and Endoguide tungsten burs, preserving pulp chamber anatomy (2). Endotracer burs (Komet; sizes 04–14) are reserved for isthmus cleaning rather than cavity preparation due to their small diameter (1).

- MINIMALLY INVASIVE ACCESS CAVITY PREPARATION PROTOCOL: Traditional endodontic cavities (TECs), still taught in dental education, varied with tooth anatomy but followed consistent objectives: radiographic and anatomical localization of the pulp chamber center, initial drilling toward this center, complete removal of the pulp chamber roof verified with a No. 17 explorer, and identification of all canal orifices to allow unobstructed instrument access (8). In contrast, minimally invasive access cavities (MIACs) are increasingly advocated to preserve tooth structure. Protocols vary by tooth type but share a conservative philosophy. For anterior teeth, access is shifted incisally to reduce cavity size while maintaining alignment with the tooth axis; for posterior teeth, a small, centered cavity is created at the occlusal convergence of canal axes, ensuring biological objectives of root canal therapy are not compromised (1). MIAC application is limited by tooth position and angulation, mouth opening, anatomical complexity, and canal calcification (1). Despite protocol variations (Plotino et al., Saygili et al.), a common goal is maximal preservation of the pulp chamber soffit and peri-cervical dentin (8). Some approaches use targeted perforations directly over canal orifices, with CBCT-assisted planning to project orifice positions perpendicularly onto the occlusal surface for precise, conservative access (8).

- MINIMALLY INVASIVE ACCESS CAVITY TECHNIQUES: Cone-Beam Computed Tomography (CBCT): Solovyev et al. (2015) used CBCT to analyze MIACs and root canal anatomy in canines, premolars, and molars (11). CBCT scans of teeth indicated for endodontic treatment were digitally processed to assess canal morphology and define access cavity limits. Plaster casts of the teeth were scanned with a 3SHAPE D900 scanner to generate high-resolution digital images, which were then superimposed with CBCT data using Amira software. A custom 3D template of the molar crown was virtually designed in 3ds MAX 2009, featuring one to three openings precisely aligned with projected canal orifices on the occlusal surface. Hole directions followed straight canal sections to allow direct instrument access, and diameters were matched to the corresponding bur (11). **Microguided Endodontics:** It was confirmed in 2017 by Connert et al. as precised for mandibular anterior teeth, particularly in cases of pulp canal calcification. This technique used a 3D-printed template with sleeves to guide the bur to the calcified canal (12). In 2018, John Wiley and colleagues employed this method for minimally invasive access cavity preparation in mandibular incisors with canal calcification and apical periodontitis, utilizing virtual planning through CBCT and surface scanning (13). Joe (2018) also combined CBCT and intraoral scanning to locate calcified canals in complex cases (14). This approach preserved dental structure and reduced errors, leading to improved long-term prognosis. While the planning time was significant, chairside treatment was quick, and the costs were offset by reduced errors and the prevention of more expensive treatments like implants (13). Limitations included the space required for the guide and bur, making it impractical for posterior regions, as well as risks of dentin microfractures and increased temperature during root surface drilling, which could harm the periodontal ligament (13). Additionally, the increased radiation dose from CBCT was a concern, though newer machines offered lower doses (13). **Guided Microendodontic Technique Using a Clinical Simulator:** involved using plaster models of dental arches with preserved human teeth integrated into them. In a 2018 study by Roch Veyssyre, an endodontic trephination guide, similar to a surgical implant guide, was used on intact human incisors. This guide, coupled with CBCT scans, allowed for precise depth control and tissue preservation, minimizing risks during treatment (15). It could be particularly helpful for general practitioners and in situations where visual aids were unavailable. Even with canal mislocalization, the risk of root perforation was low, and complications could be managed through re-planning. The study observed a 75% immediate success rate, with angular deviation being the main failure factor due to inaccuracies in the guide impression. However, the ability to manage intraoperative complications led to successful re-localization of the canal in cases of therapeutic failure, resulting in high success rates typically achieved only by specialist endodontists working under an operating microscope. **Guided Endodontic Templates**: According to Roméo Berut (2021), alongside optical aids and ultrasonic inserts, some practitioners nowadays used custom-made 3D-printed endodontic guides to access root canals while preserving maximum dental tissue. These guides were designed based on 3D radiographic data, allowing precise determination of the axis of access in all three spatial dimensions (10). Following a radiographic simulation of the drilling axis, a surgical guide could be printed using a 3D printer. This approach proved highly valuable for negotiating calcified canals, accessory canals, and main root canals, significantly reducing chair time and minimizing the risks of iatrogenic damage, deviation, or perforation. While the principal mirrors that of guided microendodontics, the key distinction lied in application guided microendodontics was performed without visual assistance on extracted, mineralized incisors placed in specially designed clinical simulators.

-**NON-INVASIVE CANAL SHAPING:** Minimal access cavities support modern minimally invasive endodontics, but preserving coronal dentin must not compromise canal shaping or disinfection, prompting a shift toward minimally invasive shaping. Roméo Berut (2021) highlighted flexible nickel-titanium (NiTi) rotary instruments with 2% taper, preventing apical blockages and reducing fracture risk, especially at the tip; single-use or thermally treated files further improved fatigue resistance (10). Solovyov et al. emphasized that flexible NiTi instruments allowed mechanized shaping, accelerating treatment and enabling safe instrumentation of curved canals even with minimal access openings (11). Alovisi et al. demonstrated that the ProGlyder instrument’s significant taper reduced stress on shaping files, preserving canal morphology during minimally invasive protocols (10).

Regarding dental structure impact, conservative access cavity designs (CAMI) generally preserve fracture resistance. Krishan et al. (2014) found molars and premolars with CAMI had similar strength to intact teeth, unlike traditional access cavities (TAC), highlighting cervical dentin preservation (16). Allen and Meyer (2018) 3D FEA showed higher stress in TAC teeth, particularly in pre-cervical regions, supporting CAMI's role in maintaining occlusal load transfer (17). Joe (2019) extended FEA confirmed CAMI reduced cervical stress and improved load-bearing in maxillary first molars (20). However, other studies reported limited benefits: a 2018 JOE study found no fracture resistance improvement in maxillary molars with complex mesiobuccal roots (21); Wiley et al. (2020) observed no effect in mandibular incisors (22); and multiple studies (Chlup et al., 2017; Silva et al., 2020; Moore et al., 2016; Rover et al., 2017; Sabeti et al., 2018) reported no significant effect in premolars and molars. Overall, CAMI improves fracture resistance in some teeth, but benefits are not universal, particularly in anatomically complex cases.

Findings:

- CAMI showed higher fracture resistance in 10 studies.
- No difference was found in 18 studies.

Most studies involved CAC, CAN, and Truss access designs.

Tableau III: Methodological details of studies reporting on the influence of minimally invasive access cavity preparation on tooth fracture resistance. (6)

Studies	**Tooth type**	**Comparison of tooth fracture resistance between CAMI and TAC**
Abou-Elnaga et coll (2019)	Mandibular first molars	
Saberi et coll (2020)	Maxillary molars	CA Truss > TAC
Chlup et coll (2017)	Mandibular premolars	
Corsentino et coll (2018)	Mandibular molars	
Ivanoff et coll (2018)	Premolars	
Moore et coll (2016)	Mandibular molars	
Plotino et coll (2017)	Maxillary molars	
Roperto et coll (2019)	Maxillary first premolars	CAT=CAC
Rover et coll (2017)	Maxillary molars	
Sabeti et coll (2018)	Mandibular molars	
Silva et coll (2020)	Premolars	
Krishan et coll (2014)	Premolars/Molars	
Makati et coll (2018)	Maxillary molars	
Ozyurek et coll (2018)	Molars	CAT=CAN
Krishan et al (2014) Plotino et al (2017)		

Makati et al (2018) Abou-Elnaga et al (2019) Saberi et coll (2020)	Not specified	CAC > CAT
Moore et al (2016) Chlup et al (2017) Ivanoff et al (2017) Rover et coll (2017) Corsentino et al (2018) Ozyurek et al (2018) Sabeti et coll (2018) Roperto et al (2019) Silva et al (2020)	Not specified	No difference

On root canal disinfection: Conservative access cavities (CAMI) can compromise root canal disinfection. Siqueira and Roccomo (2008) reported that residual pulp tissue after cleaning may serve as a persistent infection source [6]. Neelakantan et al. (2018) found more pulp remnants in mandibular molars with truss access cavities compared to traditional access cavities (TAC), interfering with mechanical instrumentation and irrigation flow [6]. Vieira et al. (2020) showed that conventional irrigation was less effective in teeth with conservative access cavities (CACs), leaving higher bacterial loads in mandibular incisors post-shaping and disinfection [23]. John Wiley et al. (2020) confirmed that smaller access designs (CAN, truss) reduced irrigation efficiency, leaving more pulp tissue and debris, although the impact on bacterial reduction remained unclear [6]. Challenges are greater in oval-shaped canals, where conventional instruments only contact the central lumen, leaving untouched areas. New NiTi rotary systems, such as TRUShape 3D Conforming Files, have been developed to enhance disinfection in complex anatomies, preserving dentin and improving bacterial removal compared to conventional NiTi systems, though their shaping ability remains controversial [22].

Table IV: Number of teeth positive for E. faecalis after root canal disinfection of mandibular incisors through a CAT and CAC. (23)

Number of teeth positive for E. Faecalis Access cavity type	Before Treatment	After Treatment	Significant difference
Traditional access cavity	**28/28 (100%)**	**14/28 (50%)**	**YES (*p* < 0,01)**
Conservative access cavity	**29/29 (100%)**	**25/29 (86%)**	**YES (*p* < 0,01)**
Significant difference	**NO (*p* > 0,05)**	**YES (*p* < 0,01)**	

In the same context, a 2020 ex vivo study by JOE compared root canal shaping and disinfection in CAMI versus conventional access teeth (CAT) [23]. CAMI was created on the free tooth margin to preserve cingulum and coronal dentin. XP EndoShaper, which adapts to canal anatomy via a serpentine design, contacted more canal walls without excessive dentin removal, making it suitable for minimally invasive treatment [24]. However, in CAMI, disinfection was significantly compromised because the restricted access interfered with the XP EndoShaper's entry angle and movement. Adjunctive laser-activated irrigation improved outcomes. Kimura et al. (2017) demonstrated that Erbium:YAG laser activation of NaOCl applied shear stress to canal walls, achieving up to 99.2% bacterial reduction while preserving tooth structure [25,26,27]. Diode laser-activated NaOCl also outperformed ultrasonic activation in eliminating E. faecalis biofilms, debris, and dentin mud, and penetrated dentinal tubules more effectively [28]. Overall, CAMI techniques (CAC, truss cavities) negatively impact disinfection, especially in necrotic teeth. While CAMI may reduce fracture risk, the goal of dentin preservation is questionable if it compromises effective canal cleaning and debridement.

On root canal obturation: Studies show mixed results regarding obturation in conservative access cavities (CAMI). Silva et al. (2020) and Xia et al. (2020) reported no difference in obturation quality between CAMI and traditional access cavities (TAC/CAT) in premolars (22,29). However, John Wiley et al. (2020) observed more voids in CAMI obturations, which could harbor microorganisms and increase failure risk. Limited access complicates the use of thermocompactors, especially in oval canals, and interferes with single cone and continuous wave techniques, prompting recommendation of lateral warm condensation for CAMI-treated teeth (22). Similarly, Niemi et al. (2016) noted that minimal access hinders vertical warm obturation, supporting lateral warm condensation, particularly in mono-radicular teeth (30).

-DANGERS AND LIMITATIONS OF MINIMALLY INVASIVE APPROACHES:

Minimally invasive access cavities (CAMI) aim to preserve coronal dentin but carry significant risks:

Apical transport: CAMI can cause canal deviation, especially in curved canals (palatal canals of maxillary molars, mesial canals of mandibular molars). Studies showed larger curvature angles and increased pressure on instruments, raising apical transport risk (John Wiley et al., 2020; Eaton et al., 2015; Zhang et al., 2019; Xia et al., 2020). Some studies found no significant difference (Freitas et al., 2020), but transport remains a potential downside.

Instrument fracture: Preserving coronal structure increases canal curvature, raising fracture risk. Curvatures >30° show a 35% higher incidence of file breakage (Zhang et al., 2019). Fractured instruments require removal, causing unnecessary dentin loss and undermining minimally invasive goals (John Wiley et al., 2020).

Procedural complexity: CAMI complicates root canal treatment, making it more time-consuming and prone to procedural accidents, which can affect long-term prognosis and contradict mechanized simplification trends.

Canal identification challenges: Small CAMI cavities hinder visualization of canal orifices, particularly second canals in lower incisors, canines, or complex anatomy. Preoperative imaging (CBCT) and optical aids with coaxial lighting are recommended (John Wiley et al., 2020; Eve Laurent, 2020).

Iatrogenic errors and aesthetic issues: Extremely conservative access can cause false paths, canal deviation, and discoloration. CACs are more likely to create false canals, particularly in palatal roots of maxillary molars (Rover et al., 2017). TACs better preserve canal anatomy with less deviation (Alovisi et al., 2012).

CONCLUSION

Minimally invasive endodontics, inspired by restorative principles, seeks to preserve dental tissue while maintaining effective disinfection, shaping, and obturation. Unlike traditional access cavities, which remove substantial dentin and weaken teeth, CAMI aims for conservative access. However, successful applications require balancing tissue preservation with procedural safety and efficacy. Further studies are needed to support routine clinical use and incorporation into dental education.

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