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Current status and future directions of endodontic access cavity preparation: A narrative review

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Abstract
Endodontic access cavity preparation represents a critical stage of root canal treatment because it establishes the pathway for identification, negotiation, cleaning, shaping, disinfection, and obturation of the root canal system. Traditionally, access cavity preparation has emphasized complete removal of the pulp chamber roof and establishment of straight-line access to facilitate instrumentation. However, increasing recognition of the biomechanical importance of remaining tooth structure has led to the development of minimally invasive and conservative access cavity concepts. Preservation of pericervical dentin and other strategically important structures has become a central objective of contemporary endodontic treatment. At the same time, advances in cone-beam computed tomography, optical magnification, dental operating microscopes, ultrasonic instruments, flexible nickel-titanium systems, laser technology, and enhanced irrigation have expanded the possibilities for conservative access preparation. More recently, static-guided and dynamic-guided endodontics have enabled digitally planned access to anatomically complex and calcified root canal systems, while artificial intelligence has shown potential for automated recognition and characterization of root canal anatomy. Nevertheless, the available evidence does not establish a universally superior access cavity design. Excessively conservative preparations may compromise canal detection, instrumentation, irrigation, and disinfection, whereas unnecessarily extensive preparations may weaken the remaining tooth structure. Therefore, contemporary access cavity preparation should be individualized according to tooth morphology, canal anatomy, restorative status, calcification, remaining tooth structure, and available technology. This narrative review discusses the evolution of access cavity preparation, current concepts, technological advancements, clinical outcomes, complications, and future directions, with emphasis on achieving an appropriate balance between adequate endodontic access and preservation of structurally important dental tissues.

Keywords: Access cavity, conservative access cavity, minimally invasive endodontics, pericervical dentin, cone-beam computed tomography, dental operating microscope, guided endodontics, artificial intelligence

Introduction

The primary objective of root canal treatment is to control microbial infection and manage apical disease through effective cleaning, shaping, disinfection, and obturation of the root canal system. Adequate access to the root canal system is essential for achieving these objectives. Access cavity preparation is therefore not merely an initial mechanical procedure but a fundamental determinant of the subsequent quality and predictability of endodontic treatment. Inadequate access may compromise canal identification and instrumentation and increase the risk of procedural errors, including missed canals and perforation [1, 2].

Historically, access cavity preparation was based on standardized geometric outlines for individual teeth, with an emphasis on complete deroofing of the pulp chamber and establishment of straight-line access. The conventional philosophy prioritized visibility, instrument control, and reduction of procedural difficulties. However, this approach was subsequently questioned because extensive removal of coronal and cervical dentin may adversely affect the structural integrity of endodontically treated teeth [3, 4].

The development of minimally invasive dentistry has consequently shifted attention toward preservation of healthy tooth structure. Contemporary access cavity concepts attempt to reduce unnecessary dentin removal while maintaining adequate access for canal localization, instrumentation, irrigation, and obturation. Conservative, ultraconservative, truss, caries-driven, and restorative-driven access designs have subsequently been introduced and incorporated into contemporary endodontic terminology [5, 10].

The evolution of access cavity preparation has been accompanied by major technological developments. Three-dimensional imaging, magnification, illumination, ultrasonic instrumentation, heat-treated nickel-titanium instruments, laser-assisted procedures, and digitally guided endodontics have made it increasingly possible to locate and negotiate complex canal systems through smaller access preparations [10, 20, 21, 22].

This review discusses the current status of endodontic access cavity preparation, critically considers the evidence supporting conventional and minimally invasive designs, and examines emerging technologies that may influence the future of access cavity preparation.

Evolution of Endodontic Access Cavity Preparation

The traditional access cavity was developed around the principle that direct, unobstructed access to the root canals would facilitate instrumentation and reduce procedural errors. Conventional preparation involves removal of the pulp chamber roof and dentinal projections that interfere with instrument placement, with the objective of creating a smooth pathway toward the canal orifices [2, 11].

Traditional access cavity preparation generally emphasizes three fundamental objectives: complete unroofing of the pulp chamber, establishment of an unobstructed pathway to the root canal orifices, and preservation of sound tooth structure whenever possible [5, 10].

The concept of minimally invasive endodontics challenged this conventional philosophy. Clark and Khademi emphasized preservation of the pulp chamber roof or "soffit" and pericervical dentin, proposing that these structures contribute to the mechanical stability of the endodontically treated tooth [3]. Subsequent access designs attempted to further reduce the dimensions of the access cavity.

Silva et al. proposed a universal nomenclature for minimal access cavity preparations, including Traditional Access Cavity (TradAC), Conservative Access Cavity (ConsAC), Ultra-conservative Access Cavity (UltraAC), Truss Access Cavity (TrussAC), Caries-driven Access Cavity (CariesAC), and Restorative-driven Access Cavity (RestoAC) [5]. This classification has helped provide greater consistency when comparing different access cavity designs in research and clinical practice.

Anatomical Considerations in Access Cavity Preparation

Successful access cavity preparation requires a detailed understanding of both external tooth morphology and internal root canal anatomy. Preoperative assessment should include evaluation of tooth angulation, root morphology, pulp chamber position, canal curvature, previous restorations, calcification, and potential anatomical variations. Periapical radiographs remain fundamental for initial assessment, while additional horizontal angulations may provide information regarding superimposed roots and canals [15].

The complexity of root canal anatomy varies considerably among individual teeth. Mandibular incisors may contain a second lingual canal, mandibular molars may present additional distal or middle mesial canals, and maxillary molars frequently contain a second mesiobuccal canal [11-13]. Failure to recognize these anatomical variations may result in untreated canals and persistent microbial infection.

The maxillary first molar is particularly important because of the frequent presence of an MB2 canal. Clinical studies have demonstrated that MB2 canals may be identified in a substantial proportion of maxillary first and second molars [12, 13, 18]. Adequate access, magnification, illumination, and careful exploration of the pulpal floor can significantly improve canal detection.

Thus, access cavity design should be determined by the anticipated anatomy rather than by a rigid geometric template. This anatomy-driven approach represents one of the most important principles of contemporary access preparation.

Pericervical Dentin and Structural Preservation

The concept of pericervical dentin has become central to contemporary access cavity philosophy. Pericervical dentin is generally described as the dentin extending approximately 4 mm coronal and 6 mm apical to the alveolar crest. It acts as an important stress-transmitting region between the crown and root and contributes to the biomechanical integrity of the tooth [3, 4].

Endodontically treated teeth are exposed to cumulative structural loss resulting from caries, previous restorations, fracture, access cavity preparation, and root canal instrumentation. Excessive removal of dentin may increase stress concentration and susceptibility to fracture [3, 6-9]. Therefore, preservation of strategically important dentin has become an important component of contemporary endodontic treatment.

Conservative access cavity designs attempt to preserve greater amounts of coronal dentin and pericervical dentin by reducing access dimensions and retaining portions of the pulp chamber roof. The proposed biomechanical advantage is based on preservation of tooth structure rather than on the access cavity geometry itself.

However, the clinical superiority of minimally invasive access cavities remains uncertain. While several laboratory studies have reported increased fracture resistance following conservative access preparation, other studies have demonstrated no significant difference compared with traditional access cavities [6-9]. A systematic review by Silva et al. also concluded that the available in vitro evidence was insufficient to establish a consistent fracture-resistance advantage of contracted access cavities [7].

Consequently, preservation of dentin should not be pursued at the expense of adequate canal identification and disinfection.

Contemporary Access Cavity Designs

Traditional Access Cavity

Traditional access cavities provide relatively unrestricted visualization of the pulp chamber and root canal orifices and facilitate straight-line instrument access. Their principal advantages include predictable canal localization, easier instrumentation, and reduced coronal interference. However, greater removal of tooth structure may compromise structural integrity when performed unnecessarily [10].

Cone-beam Computed Tomography

CBCT has substantially expanded the clinician's ability to evaluate three-dimensional root canal anatomy. Conventional periapical radiography provides a two-dimensional image of a three-dimensional structure and may therefore fail to reveal superimposed canals, complex root morphology, calcifications, or unusual anatomical configurations [15].

CBCT may assist in determining the number and morphology of roots and canals, locating additional canals, assessing canal curvature, evaluating calcification, and identifying complex developmental anomalies. It may therefore be particularly useful when conventional radiographs do not provide sufficient information for treatment planning. However, CBCT should not be considered a routine imaging modality for every endodontic case. Its use should be justified according to the individual clinical situation, with appropriate selection of field of view and exposure parameters. The additional diagnostic information should be expected to influence diagnosis or treatment planning.

Magnification and Illumination

The human eye has limited ability to visualize structures within the root canal system. Magnification devices improve visualization of fine anatomical details and may facilitate conservative access cavity preparation [16-18].

Loupes provide relatively simple and portable magnification, whereas the dental operating microscope offers greater magnification, improved illumination, and superior visualization. The microscope is particularly valuable for identifying calcified canals, additional canal orifices, pulp stones, cracks, perforations, and other anatomical details [16-18].

Magnification may be particularly important when conservative access cavities are used because preservation of the pulp chamber roof can restrict illumination and visibility. The combination of enhanced illumination and magnification can therefore compensate for some of the limitations associated with reduced access dimensions.

Ultrasonic Instrumentation

Ultrasonic instruments have become an important adjunct in minimally invasive access preparation. Unlike rotary burs, ultrasonic tips provide controlled, nonrotary cutting and allow precise removal of small amounts of dentin under direct visualization. They are particularly useful for refining access cavities, removing calcifications and pulp stones, troughing developmental grooves, and locating hidden canals such as the MB2 [20-21]. However, ultrasonic instruments should be used conservatively. Excessive power or prolonged instrumentation may result in unnecessary dentin removal, alteration of chamber anatomy, or instrument fracture. Thus, their principal value lies in controlled and selective dentin removal rather than extensive cavity preparation.

Heat-treated Nickel-titanium Instruments

Modern nickel-titanium instruments with improved metallurgy and flexibility have expanded the feasibility of instrumentation through conservative access cavities. Heat-treated NiTi systems demonstrate enhanced flexibility and fatigue resistance and may better negotiate curved canals through restricted access [10]. Nevertheless, coronal interferences created by extremely conservative access designs may increase instrument stress and potentially compromise cyclic fatigue resistance. Therefore, improvements in instrument metallurgy do not eliminate the need for an adequately designed access cavity.

Laser Technology

Multiple laser systems have been investigated in endodontics, including Er:YAG, Er,Cr:YSGG, Nd:YAG, Nd:YAP, CO_2, and diode lasers. These systems differ in wavelength, tissue interaction, penetration, and clinical applications. Er:YAG and Er,Cr:YSGG lasers demonstrate strong interaction with water and have been investigated for hard-tissue preparation and endodontic disinfection. Nd:YAG and diode lasers have been investigated primarily for antimicrobial and disinfection applications [20]. Laser-assisted irrigation and disinfection may be particularly relevant to conservative access cavities because reduced chamber dimensions may restrict irrigant exchange. However, excessive laser energy may result in undesirable thermal effects and structural changes. Therefore, appropriate parameters and clinical indications remain essential.

Guided Endodontics

Guided endodontics represents an important development in the management of difficult root canal anatomy, particularly calcified and obliterated canals. It combines CBCT imaging with digital surface scanning and computer-assisted planning to determine an appropriate drilling trajectory. Guided procedures can broadly be classified as static and dynamic navigation [22-24].

Static-guided Endodontics

Static guidance involves fabrication of a customized three-dimensional guide based on preoperative CBCT data and surface scanning. A virtual bur is positioned within the digital model, and the planned trajectory is transferred to a physical guide using CAD/CAM and three-dimensional printing [22-24].

Static-guided access may improve accuracy and reduce unnecessary removal of sound tooth structure, particularly in severely calcified canals. It may also reduce the risk of perforation by directing the bur along a predetermined pathway. Nevertheless, errors may arise at several stages of the digital workflow, including CBCT artefacts, scanning inaccuracies, image-registration errors, planning errors, and dimensional inaccuracies during three-dimensional printing. Posterior access may also be complicated by limited vertical space and guide interference.

Dynamic Navigation

Dynamic navigation provides real-time guidance of the access bur using optical tracking and preoperative CBCT data. The position and angulation of the handpiece are continuously monitored and displayed relative to the digitally planned drilling trajectory [23, 24]. Unlike static guides, dynamic navigation does not require fabrication of a physical guide and allows modifications to the drilling trajectory during the procedure. Because the current evidence base is limited, further comparative clinical studies are required before dynamic navigation can be considered a routine component of endodontic practice.

Unlike static guides, dynamic navigation does not require fabrication of a physical guide and allows modifications to the drilling trajectory during the procedure. Early studies have demonstrated greater precision compared with freehand access in selected experimental models. One study reported mean angular deviation of 4.8° and maximum mean distance deviation of 0.34 mm with dynamic navigation compared with 21.2° and 0.88 mm, respectively, for freehand preparation [15].

Artificial Intelligence in Access Cavity Preparation

Artificial intelligence is an emerging area of interest in endodontics. Machine-learning and deep-learning models, particularly convolutional neural networks, have been investigated for automated analysis of three-dimensional dental imaging.

Potential applications include segmentation of roots and canals, identification of complex canal configurations, estimation of the number of canals, reconstruction of root canal systems, recognition of developmental anomalies, landmark detection, and estimation of anatomical parameters. AI-assisted analysis may eventually support preoperative access cavity planning by providing automated anatomical maps and identifying areas of potential canal complexity. In combination with CBCT and digital surface scanning, such systems could contribute to individualized and minimally invasive access preparation. However, clinical implementation remains at an early stage. Larger and more diverse datasets, standardized imaging protocols, external validation, and clinically meaningful outcome measures are required before AI systems can be reliably integrated into routine endodontic practice.

Clinical Outcomes: Traditional versus Conservative Access

The central controversy surrounding contemporary access cavity preparation is whether the structural advantages of conservative designs outweigh their potential limitations in canal detection, instrumentation, irrigation, and disinfection.

Several laboratory investigations have reported greater fracture resistance following conservative access preparation. Jiang et al. demonstrated reduced cervical stress concentration in conservative access cavities using finite element analysis [6]. Krishan et al. and Plotino et al. similarly reported improved fracture resistance with conservative or ultraconservative designs [25, 26].

Conversely, other investigations have failed to demonstrate a significant difference between conservative and traditional designs. Rover et al. and Moore et al. reported comparable fracture resistance between access designs, while Silva et al. concluded that evidence supporting the superiority of contracted access cavities remains insufficient [7, 9, 27].

The effect of access design on instrumentation is similarly inconsistent. Some studies have suggested that restricted access may interfere with instrument placement and maintenance of canal curvature, whereas others have found no significant difference in instrumentation efficacy [25-27].

Complications Associated with Access Cavity Preparation

Access-related complications remain important causes of endodontic failure. Underextension may result in inadequate visualization, missed canals, and compromised instrumentation, whereas overextension may unnecessarily weaken the tooth. Other complications include perforation, gouging, excessive dentin removal, instrument separation, and loss of orientation.

Perforation

Perforation represents an undesirable communication between the root canal system and the external tooth surface. It may occur during access preparation or canal negotiation and is particularly common in anatomically complex or calcified teeth [14]. Accurate preoperative assessment, maintenance of the long axis of the tooth, appropriate access dimensions, magnification, illumination, and careful recognition of the pulp chamber floor are essential for prevention. When perforation occurs, prognosis depends on factors including location, size, contamination, timing of repair, and periodontal involvement. Prompt repair using biocompatible materials such as MTA or contemporary calcium-silicate materials may improve the prognosis.

Missed Canals

Failure to locate and treat all root canals remains an important cause of persistent or recurrent endodontic disease. The MB2 canal in maxillary molars and additional distal canals in mandibular molars are common examples. Calcification and inadequate access may further complicate canal detection. Magnification, ultrasonics, appropriate anatomical knowledge, dyes, transillumination, careful exploration, and CBCT when indicated can improve the detection of difficult canals [12, 20, 21].

Future Directions

The future of endodontic access cavity preparation is likely to involve increasing integration of three-dimensional imaging, magnification, digital planning, guided navigation, artificial intelligence, and improved instrumentation.

CBCT may provide increasingly precise three-dimensional anatomical information, while digital surface scanning can allow this information to be integrated with the external morphology of the tooth. Static and dynamic guided techniques may consequently facilitate increasingly precise access preparation in teeth with calcified or complex canal systems.

Artificial intelligence may further automate the identification of canal anatomy and provide decision-support systems for access planning. Future systems may potentially generate patient-specific access trajectories based on the three-dimensional anatomy of an individual tooth.

At the same time, technological development should not replace fundamental anatomical knowledge. Digital technologies depend on accurate imaging, appropriate interpretation, and sound clinical judgment. Errors in imaging, registration, planning, or execution may still result in procedural complications.

The future therefore lies not simply in making access cavities smaller, but in making them more precise, anatomy-driven, biologically respectful, and clinically appropriate.

Clinical Significance

Importantly, many available studies are laboratory investigations and may not accurately reproduce clinical conditions. Differences in tooth selection, access dimensions, instrumentation systems, irrigation protocols, obturation techniques, restorative procedures, and loading conditions contribute to heterogeneity among studies.

Therefore, there is currently insufficient evidence to support a universal recommendation that conservative access cavities should replace traditional designs.

Conclusion

Endodontic access cavity preparation remains a fundamental and decisive stage of root canal treatment. Although traditional access cavities provide predictable visualization and facilitate instrumentation, contemporary endodontics increasingly emphasizes preservation of pericervical dentin and other structurally important tooth tissues.

Current evidence does not establish a universally superior access cavity design. Conservative access cavities may provide structural advantages in selected situations, but excessively restricted access may compromise canal detection, instrumentation, irrigation, and disinfection. The available evidence is further limited by the predominance of laboratory studies and considerable methodological heterogeneity.

Technological developments including CBCT, magnification, dental operating microscopes, ultrasonics, improved NiTi instruments, lasers, static-guided endodontics, dynamic navigation, and artificial intelligence have substantially expanded the possibilities for precise and minimally invasive access preparation.

Ultimately, there is no universally ideal access cavity. The appropriate design should be individualized according to tooth morphology, canal anatomy, calcification, restorative status, remaining tooth structure, clinical circumstances, and available technology. Contemporary access preparation should therefore be regarded as an anatomy-driven, technology-assisted, and biologically respectful procedure that balances adequate access with preservation of tooth structure and long-term tooth survival.

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