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Endodontic Access Cavity Designs: A Review of Traditional and Minimally Invasive Approaches

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ABSTRACT
Endodontic access cavity preparation is a critical step that allows for straight-line access to the root canal system during root canal treatment. Traditional guidelines have called for the removal of significant amounts of tooth structure to create a straight-line access pathway. However, excessive removal of dentin can substantially weaken the remaining tooth and increase the risk of vertical root fractures. As such, there has been growing interest in minimally invasive or "conservative" access cavity designs that aim to preserve pericervical dentin and remaining tooth structure while still providing adequate access for canal instrumentation and obturation. This article reviews the current literature comparing traditional endodontic access cavities versus minimally invasive contracted access designs. It examines the impacts of these different access approaches on the efficacy of canal instrumentation and irrigation, quality of root canal fillings, biomechanical behavior, and fracture resistance of endodontically treated teeth. The potential advantages and limitations of minimally invasive cavity designs are discussed, along with emerging technologies like guided endodontics that may enable truly individualized conservative access cavities tailored to each patient's unique root canal anatomy.

Keywords: instrumentation, Traditional, minimally, dentin

INTRODUCTION
Access cavity preparation is a critical first step in root canal treatment, allowing straight-line access to the root canal system for cleaning, shaping, and obturation (Gutmann & Fan, 2016). Proper access design facilitates complete debridement, disinfection, and three-dimensional filling of the intricate root canal anatomy. However, excessive removal of sound tooth structure during access cavity preparation can significantly weaken the remaining tooth structure, increasing the risk of vertical root fractures and long-term failure (Silva et al., 2020a). As such, there has been growing interest in minimally invasive "conservative" or "contracted" endodontic access cavity designs that preserve more pericervical dentin compared to traditional methods (Clark & Khademi, 2010). This article reviews the literature on traditional versus minimally invasive endodontic access cavity designs, examining their impacts on instrumentation and disinfection efficacy, quality of root fillings, biomechanics, and fracture resistance.

Traditional Access Cavity Designs
Traditional endodontic accesses aim to provide a straight pathway to locate canal orifices, allow debridement, and facilitate shaping and filling (Watson, 2009). In anterior teeth, the traditional access is triangular/ovoid on

the lingual surface, with maxillary incisors using the incisal edge as a guide and mandibular incisors slightly off-center (LaTurno & Zillich, 1985; Zillich & Jerome, 1981; Mauger et al., 1999; Madjar et al., 1989).

For posterior teeth, guidelines call for removing overlying enamel and pulp chamber roof, creating a straight pathway paralleling the long axis (Gutmann & Fan, 2016; Clark & Khademi, 2010). This "straight-line" access extends from lingual grooves (maxillary molars) or just lingual to buccal cusps (mandibular molars) (Watson, 2009). Complete roof removal improves visualization, locating canals, flaring the coronal thirds, and accommodating instruments (Clark & Khademi, 2010).

While providing ideal access, traditional cavities require significant tooth structure removal, reducing fracture resistance - especially combined with aggressive tapers (Saber et al., 2020; Zhang et al., 2019; Plotino et al., 2017). Loss of marginal ridge integrity and pericervical dentin are key contributors to reduced fracture resistance and higher vertical root fracture incidence after traditional accesses (Clark & Khademi, 2010; Plotino et al., 2017). Hence, there is increasing interest in conservative "minimally invasive" access designs.

Minimally Invasive Access Cavities

Minimally invasive "contracted" accesses aim to preserve sound tooth structure while allowing adequate access, cleaning, shaping, and filling (Silva et al., 2020b). These conservative designs involve selective caries removal using burs, microscopes, ultrasonic tips, and/or CBCT-guided endodontics to avoid unnecessary pericervical dentin, roof, and marginal ridge removal (Manigandan et al., 2020; Dianat et al., 2020; Lara-Mendes et al., 2018a, 2018b).

Examples include the "orifice-directed dentin conservation" access - creating a minimal access just large enough to unroof main canal orifices while preserving pericervical dentin (Neelakantan et al., 2018). The "truss"/"boxed" access maintains an intact pulpal floor, removing only overhanging dentinal shelves (Barbosa et al., 2020; Moore et al., 2016). The "ninja access" focuses on preserving pericervical dentin and removing only overlying roof to debride the chamber (Silva et al., 2020b; Loureiro et al., 2020).

Multiple studies evaluated impacts of these conservative accesses versus traditional designs. Generally, minimally invasive approaches appear to allow adequate instrumentation, irrigation, and filling (Neelakantan et al., 2018; Barbosa et al., 2020; Rover et al., 2020; Augusto et al., 2020; Xia et al., 2020). Computational and experimental models also suggest superior biomechanical behavior and fracture resistance compared to traditional accesses, especially in larger multi-rooted teeth (Wang et al., 2020; Jiang et al., 2018; Allen et al., 2018; Guler, 2020; Maske et al., 2020; Sabeti et al., 2018).

Instrumentation and Irrigation Efficacy

Several studies found no significant differences in instrumentation ability, debris extrusion, or irrigant penetration between minimally invasive and traditional access cavities in anterior and premolar teeth (Neelakantan et al., 2018; Rover et al., 2020; Augusto et al., 2020; Xia et al., 2020). Barbosa et al. (2020) reported similar bacterial reduction in mandibular molars regardless of access type. However, some studies noted better instrumentation in moderately curved mesial canals of molars using traditional versus contracted accesses (Rover et al., 2017; Krishan et al., 2014).

The use of microscopes, ultrasonics, and CBCT guidance may help mitigate instrumentation challenges associated with minimally invasive accesses (Manigandan et al., 2020; Webber et al., 2020; Azim et al., 2016). Dynamic navigation systems have also shown promising results in locating calcified canals and minimizing excessive dentin removal during access preparation (Dianat et al., 2020; Nahmias, 2019; Lara-Mendes et al., 2018a; 2018b).

Quality of Root Canal Fillings

Most studies found no significant differences in the quality of root canal fillings between minimally invasive and traditional accesses when evaluated radiographically or using micro-CT analysis (Neelakantan et al., 2018; Barbosa et al., 2020; Rover et al., 2020; Augusto et al., 2020; Xia et al., 2020). However, a few suggested slightly better obturation quality with traditional access designs, potentially due to better visualization of root canal anatomy (Varghese et al., 2016; Rover et al., 2017).

Biomechanical Behavior and Fracture Resistance

Numerous computational modeling and experimental studies have demonstrated the favorable biomechanical behavior and greater fracture resistance of minimally invasive access cavities compared to traditional endodontic access designs (Wang et al., 2020; Jiang et al., 2018; Allen et al., 2018; Guler, 2020; D'amico et al., 2019; Ozkurt-Kayahan & Kayahan, 2016; Nissan et al., 2007; Maske et al., 2020; Sabeti et al., 2018). This advantage is particularly pronounced for larger multi-rooted teeth like molars.

The conservative endodontic access cavities preserve more tooth structure, especially the marginal ridges and thicker circumferential dentin walls that enhance cuspal stiffness and fracture resistance under occlusal loading (Saber et al., 2020; Plotino et al., 2017; Zhang et al., 2019). In contrast, the extensive loss of pericervical dentin with traditional straight-line access cavities significantly compromises the residual tooth's ability to resist deformation and fracture (Corsentino et al., 2018; Chlup et al., 2017; Yuan et al., 2016).

While most studies focused on fracture resistance following access cavity preparation alone, a few also incorporated effects of varying root canal taper preparations. These demonstrated that minimally invasive accesses combined with conservative apical taper preparations (e.g. 0.04 taper) resulted in the highest fracture resistance compared to scenarios with traditional access cavities and/or larger apical tapers (Saber et al., 2020; Krishan et al., 2014; Sabeti et al., 2018).

Standardization and Planning

There are ongoing efforts to develop standardized guidelines and planning software to optimize minimally invasive endodontic access cavities based on individualized tooth anatomy (Isufi et al., 2020; Connert et al., 2019; Lin et al., 2020; Jain et al., 2020; Makati et al., 2018). These systems use CBCT imaging data combined with computational algorithms to design conservative access outlines that provide straight-line access to all root canal orifices while maximally preserving pericervical dentin and remaining tooth structure.

Isufi et al. (2020) proposed a standardized classification system for grading minimally invasive access cavities based on the amounts of dentin and enamel removed. Connert et al. (2019) compared substance loss between guided endodontic accesses and traditional straight-line accesses using 3D-printed tooth models, finding significantly less dentin removal with the guided approach. Similar results were reported by Lin et al. (2020) comparing three different access designs on 3D digital models.

Jain et al. (2020) used simulated calcified canals in 3D printed teeth to evaluate dentin conservation between dynamically navigated versus freehand endodontic accesses. The dynamically navigated system resulted in significantly less substance removal, particularly in more challenging curved canal scenarios. Makati et al. (2018) also reported significantly greater remaining dentin thickness and fracture resistance using conservative endodontic accesses planned with CBCT guidance compared to traditional straight-line preparations.

As these computational planning tools and dynamic navigation systems continue to evolve, they may help overcome some of the historical challenges of visualizing root canal anatomy through contracted endodontic accesses. Combined with advances in imaging, illumination, and magnification, minimally invasive access cavity designs that preserve tooth structure while allowing adequate cleaning, shaping, and filling may become increasingly routine in clinical practice.

CONCLUSION

Minimally invasive or conservative endodontic access cavity designs aim to preserve as much sound tooth structure as possible while still allowing adequate localization of root canal orifices, cleaning/shaping of the root canal system, and quality obturation. Numerous studies have demonstrated no significant differences in instrumentation ability, irrigation, or filling quality between these conservative contracted accesses versus traditional straight-line approaches, particularly for anterior and premolar teeth. Some studies suggest minimally invasive accesses may present greater instrumentation challenges in severely curved canals, which can potentially be mitigated through use of microscopes, ultrasonics, and guided endodontic systems.

The key advantage of minimally invasive endodontic access designs lies in their favorable biomechanical behavior and significantly higher fracture resistance compared to traditional access cavities - especially for multi-rooted posterior teeth. By preserving pericervical dentin, marginal ridges, and circumferential dentin walls, these conservative contracted accesses enhance the residual tooth's ability to resist deformation and fracture under functional loading. This benefit is further amplified when minimally invasive accesses are combined with conservative apical taper preparations during cleaning and shaping.

As computational planning software and dynamic navigation systems continue to advance, they may enable clinicians to predictably achieve straight-line access to root canal orifices through truly minimally invasive cavity outlines customized to each patient's unique anatomic situation. Coupled with advancements in enhanced illumination, magnification, and ultrasonic instrumentation, minimally invasive endodontic access cavity designs that preserve tooth structure and fracture resistance while still allowing complete cleaning, shaping, and obturation of the root canal system may become the new clinical standard.

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