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APPLICATIONS OF STATIC GUIDED ENDODONTICS IN ACCESS CAVITY PREPARATION

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Abstract: Pulp canal calcification and complex pulp chamber anatomy can make access cavity preparation and canal localization difficult. Excessive removal of tooth structure, deviation of the access path, and root perforation may compromise subsequent treatment. By registering cone-beam computed tomography (CBCT) data with dental surface scans, static guides transfer the planned drilling direction and depth to the clinical setting, providing a preplanned access path for complex cases. This narrative review examines the technical principles, clinical applications, localization accuracy, preservation of tooth structure, and causes of failure of static-guided endodontics. Existing in vitro studies generally support improved localization accuracy, although advantages in tooth structure preservation and procedure time depend on tooth type, experimental model, guide design, and operator experience. Recent randomized clinical trials provide additional support for its use in selected cases involving calcified canals. However, one trial found no statistically significant between-group difference in clinical outcomes at one year, indicating that improved accuracy does not itself establish better long-term treatment outcomes. Image registration, guide seating, compatibility between the bur and guiding structure, and working space in posterior teeth are important determinants of performance. Static guides provide an option for selected complex access and canal localization procedures, and their value should be assessed alongside the imaging burden, planning and fabrication costs, and the ability to manage failure. Future studies should standardize outcome definitions and use multicenter clinical designs to evaluate long-term outcomes and cost-effectiveness.
Keywords: Static guides; Guided endodontics; Access cavity preparation; Pulp canal calcification; Minimally invasive endodontics; Digital dentistry

1 INTRODUCTION

Access cavity preparation aims to establish a route for subsequent cleaning and shaping based on identification of the root canal system, while preserving as much clinically important tooth structure as possible. In teeth with severe pulp canal obliteration, previous unsuccessful attempts at canal localization, or developmental anomalies, the residual canal identifiable on imaging may not have a clear correlate in the clinical field of view. This can lead operators to enlarge the preparation while searching for the canal. Static guides translate three-dimensional imaging and surface scan data into a physical guidance structure that directs the bur toward the target region along a predetermined path, providing an aid to canal localization in these cases [1-2].

Research on static guides has progressed from early case reports and accuracy experiments to comparative experiments, observational clinical studies, and randomized trials. Previous systematic reviews have identified substantial differences among studies in tooth position, degree of canal obliteration, guide design, and outcome assessment, while also noting small samples, inconsistent outcome definitions, and insufficient long-term follow-up [3]. Evaluation of static guides therefore requires separate consideration of localization accuracy, tooth structure loss, treatment efficiency, and clinical prognosis. Their overall effects cannot be summarized by canal localization success alone. This review focuses on the use of static guides for nonsurgical access cavity preparation and canal localization, and examines technical parameters and the limits of evidence interpretation.

2 LITERATURE SEARCH AND SCOPE OF THE REVIEW

This narrative review draws on PubMed literature available as of October 22, 2026. The core title/abstract search used guided endodontics, guided endodontic, and the combination of microguid with endodont. Supplementary searches used related terms, including static guidance, static navigation, template guidance, drill guide, access, calcification, and obliteration. No restrictions were imposed on the starting year or publication type. The two searches retrieved 266 and 77 records, respectively, yielding 288 records after deduplication by PMID. Representative publications on the use of physical static guides for access cavity preparation and canal localization were selected, and key methods and findings were checked against accessible full texts. Studies exclusively examining dynamic navigation, apical surgery, or post removal were not treated as core evidence. Relevant findings were extracted from comparative studies that included a static-guide group. No pooled effect estimates were calculated. Clinical studies, in vitro and ex vivo experiments, and case reports are discussed separately.

3 TECHNICAL PRINCIPLES AND WORKFLOW

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3.1 Basic Principles of Static Guidance

Static-guided endodontics uses a physical guide fabricated before treatment to control bur direction through a sleeve, rails, or other mechanical constraints, together with a planned drilling depth, to establish an access path. Its central purpose is to transfer the position of the residual canal identified on imaging accurately to the tooth, rather than to automate the entire root canal treatment. Zehnder et al. validated a localization method combining CBCT, surface scanning, and printed guides in an ex vivo study [4]. The method was subsequently adapted for clinical use, but static guides remain dependent on a predetermined trajectory; dynamic navigation instead uses a tracking system to provide real-time positional feedback [1-2].

Conventional guides are often supported by the dentition and constrain the bur through a guide sleeve. For narrow roots, miniaturized guide designs reduce the dimensions of the bur and associated components and may support more conservative access [1, 3]. Miniaturization does not, however, remove the need to consider the thickness of the remaining tooth structure, guide stability, and bur rigidity. Each design must remain appropriate to the anatomy of the target tooth and the operating conditions.

3.2 Image Registration and Access Path Planning

A typical digital workflow involves acquiring CBCT data and surface scans of the dentition, registering the datasets, identifying the residual canal lumen, planning the access path, designing and manufacturing the guide, and performing guided drilling after clinical seating. The planned endpoint is generally a region of the canal that is identifiable on imaging and permits further negotiation; it should not be equated with the anatomical apical foramen. If the canal is curved, the straight drilling path must terminate at an appropriate point, after which conventional instruments are used for further negotiation and shaping. Registration quality, the relationship between the planned trajectory and the root surface, and whether the bur and handpiece can be positioned intraorally as planned all require assessment before manufacturing [2, 4].

After guide fabrication, the fit at the supporting surfaces, reproducibility of seating, compatibility between the guidance structure and the bur, and preset depth must also be checked. A well-seated guide does not necessarily ensure that its path aligns with the canal, because image registration and manufacturing errors may be retained in the physical guide. Clinical use must also accommodate isolation, cooling, debris removal, and visibility. Once the planned endpoint has been reached, the clinician must reassess the canal rather than continue drilling deeper simply because a guide is in place. Digital planning and intraoperative verification should form a continuous process [2].

4 MAIN CLINICAL APPLICATIONS

4.1 Access Cavity Preparation and Canal Localization in Calcified Anterior Teeth

Pulp canal obliteration is the most frequently studied application of static guides. A straight access path is relatively easy to plan in anterior teeth, where supporting surfaces and operating space are also generally favorable. Early clinical applications primarily involved anterior teeth with severe posttraumatic canal obliteration, apical pathology, and difficulty with conventional canal localization; miniaturized guides later extended the approach to narrower roots [1, 3]. Radiographic evidence of canal calcification must not substitute for pulpal and periapical diagnoses. The decision to perform root canal treatment should be based on symptoms, signs, and associated pathology. The availability of a guide does not justify prophylactic access cavity preparation in a tooth without an indication for treatment [1-2].

Access route selection in anterior teeth also requires balancing the preservation of incisal and palatal tooth structure. Both incisal and palatal routes have been described for anterior teeth with canal obliteration, and a guided access path does not necessarily have to pass through the incisal edge [1, 3]. Route selection should consider the position of the residual canal, the tooth structure that can be preserved, and the requirements for subsequent cleaning and restoration. A conservative approach must remain compatible with reliable completion of treatment; the smallest possible access diameter should not be pursued as an end in itself.

4.2 Posterior Teeth and Cases with Limited Working Space

Difficulties in posterior teeth arise not only from canal obliteration but also from mouth opening, interocclusal clearance, and the presence of multiple root canals. The combined vertical space required for the guide, sleeve, bur, and handpiece may render a trajectory that can be planned preoperatively inaccessible intraorally. Static guidance has been applied to molars, but current evidence is largely case-based and does not establish that all molars are suitable for a standard guide [1, 3].

To address inadequate space, modified designs such as open or intracoronal guidance structures have been described to facilitate bur insertion, irrigation, and visibility [1, 3]. These modifications illustrate that posterior guides must meet requirements for both geometric localization and practical accessibility. Current findings are derived mainly from case reports and are insufficient to compare failure rates among modified designs or determine which design should be preferred.

4.3 Guided Localization in Complex Pulp Chamber Anatomy

Static guides can also be used to plan access in teeth with anatomical anomalies, such as dens invaginatus. Published case-based evidence describes CBCT-guided access for dens invaginatus and other anomalies [1, 3]. In such cases, the guide improves access to a specific target region and reduces unnecessary cutting during repeated exploratory attempts. Communications between anomalous structures, the extent of infection, and subsequent cleaning requirements must still be assessed independently. Establishing an access path should not be taken to mean that the entire complex root canal system has been treated.

5 EVIDENCE ON ACCESS CAVITY PREPARATION ACCURACY AND CLINICAL OUTCOMES

5.1 Localization Accuracy

The accuracy of access cavity preparation is commonly evaluated by comparing the planned and actual trajectories in terms of coronal entry deviation, bur-tip or target-end deviation, and angular deviation. Here, target-end deviation describes the positional discrepancy at the end of the drilled channel; it does not refer to deviation when the bur reaches the anatomical root apex. In an experiment involving 60 extracted teeth, Zehnder et al. reported a mean angular deviation of 1.81° [4]. This finding supports the ability of static guides to transfer planned access paths with reasonable accuracy. However, values obtained with different tooth types and imaging or measurement methods should not be used to rank techniques directly.

Comparisons between static and dynamic navigation have not established a consistent ranking applicable to all settings. Both approaches can reduce angular deviations relative to freehand preparation in laboratory settings, but results vary by model, equipment, and outcome measure [1, 3]. Angular control, preservation of tooth structure, and procedural efficiency are distinct dimensions, and an advantage in one dimension cannot replace an assessment of overall performance.

Tooth position may also affect accuracy, with posterior sites generally presenting greater access and stabilization challenges than anterior sites [1-3]. Small studies also suggest a possible association between the location of calcification and off-center drilling, but they cannot establish universal risk thresholds [3]. Reports should specify whether the unit of analysis is the patient, tooth, or access channel so that multiple channels in one tooth or multiple teeth in one patient are not incorrectly treated as entirely independent observations.

5.2 Preservation of Tooth Structure and Procedure Time

In 3D-printed models simulating calcified anterior teeth, Connert et al. achieved canal localization in 22/24 preparations in the guided group and 10/24 in the conventional group. The corresponding mean volumes of tooth structure removed were 9.8 and 49.9 mm^3, and the recorded procedure times were 11.3 and 21.8 min, respectively [5]. This experiment indicates that, in simulated cases of a particular difficulty, a planned access path can reduce unnecessary cutting during canal localization. Nevertheless, printing materials, the simulated morphology of calcification, and operator-related conditions affect the results, and the observed experimental differences should not be interpreted directly as expected clinical benefits.

Studies using natural teeth have yielded more complex findings. Some comparative experiments report less tooth structure removal with guided access in selected teeth, whereas others find no significant difference from expert freehand preparation [1, 3]. These findings do not negate the value of guidance; rather, they indicate that the expertise of the comparator and the conditions of the cases can alter its relative advantage.

Experiments using artificial teeth with normal canal spaces have sometimes shown less tooth structure removal without higher canal localization rates [1, 3]. Moreover, whether conservative access paths in model studies improve long-term fracture resistance or tooth survival cannot be determined from the volume of tissue removed alone. Time assessments must also distinguish digital data acquisition, planning, fabrication, guide placement, and actual drilling. Laboratory comparisons have shown that faster drilling is not consistent across systems or operators [1, 3]. Faster chairside drilling and greater efficiency of the overall treatment workflow should therefore be reported separately.

5.3 Comparative Clinical Studies

Li et al. randomly assigned 80 calcified teeth from 80 patients to static-guided and freehand groups, with 40 cases per group. Coronal entry deviation, target-end deviation, and angular deviation were lower in the static-guided group, but both groups ultimately achieved canal localization without perforation. Neither one-year clinical outcomes nor intraoperative pain differed significantly between the groups. Tooth structure removal was not quantified in this trial, so it cannot establish that guided access preserved more tooth structure in this clinical sample [6]. The abstract of another randomized trial involving 30 patients, reported by Ali et al., stated that all canals were localized in the static-guided group, whereas localization failed in approximately 13% of cases in the freehand group; the imaging-based measure of tooth structure loss was also lower in the static-guided group [7]. Taken together, these trials support the use of static guides in selected cases with calcified canals, but they do not establish improvements in long-term treatment outcomes or tooth survival.

The prospective single-arm trial by Torres et al. used historical external controls. The guided group included 60 teeth from 59 patients, and the freehand control group included 73 teeth from 69 patients. Canals were located in 59/60 and 59/73 teeth, respectively, with 0 and 7 perforations recorded [8]. Because case selection, treatment periods, and other conditions may have differed, this comparison does not provide the comparability afforded by randomized allocation. Together with the randomized trials, this study broadens the clinical evidence but does not by itself establish causal superiority or long-term benefit [6-8].

Small pilot and observational studies have also examined chairside time and cavity volume, but their measurement windows and endpoints differ, limiting direct pooling [3]. Representative clinical studies are summarized in Table 1. Overall, the more established evidence currently concerns the transfer of planned access paths and canal localization; effects on infection control, periapical healing, retreatment, and long-term tooth survival still require independent evaluation.

Table 1 Representative Clinical Studies of Static Guided Access Cavity Preparation

Study	Design and sample	Main observations	Interpretation
Li et al. 2025 [6]	Randomized trial 80 teeth (40/group)	Lower deviations with guidance Canals localized in both groups	No one-year outcome difference Tissue removal not quantified
Ali et al. 2026 [7]	Randomized trial 30 patients	All canals localized with guidance About 13% failed freehand	Lower imaging-based tissue loss Small sample
Torres et al. 2025 [8]	Prospective single-arm trial Historical controls (60 vs 73 teeth)	Localization: 59/60 vs 59/73 Perforations: 0 vs 7	Nonrandomized comparison No causal inference

Note: Tooth and patient counts are reported separately. Localization success, geometric deviation, tooth structure loss, and healing are distinct outcomes; sample sizes should not be combined across studies.

6 FACTORS INFLUENCING OUTCOMES OF GUIDED ACCESS CAVITY PREPARATION

6.1 Image Quality and Data Registration

CBCT must provide sufficient information to identify the target canal and root boundaries, whereas surface scans define the guide support area and seating relationship. Errors in either dataset may be incorporated into the final access path during registration. Image resolution, registration, and manufacturing parameters can affect angular and linear deviations, and different components may influence different directions of error [2, 9]. These findings indicate that digital accuracy should be assessed across the entire workflow; the printer's nominal layer thickness alone cannot represent the accuracy ultimately achieved clinically. Imaging parameters must also balance the required diagnostic information against radiation exposure. Laboratory findings favoring higher resolution do not justify indiscriminately increasing clinical acquisition settings.

The methods used to assess accuracy also affect comparability across studies. Postoperative intraoral scanning and CBCT-based measurements have both been used to assess access path deviations [1, 3]. However, meaningful comparisons require validation of the scanning, impression, or access path reconstruction methods and a clear statement of whether the measurement concerns the drilling axis, cavity surface, or volume difference.

6.2 Guiding Structures and Manufacturing Methods

Guide design must account for support stability, mechanical guidance, and clinical feasibility. Sleeved, sleeveless rail-guided, and nonrestrictive structures have all been investigated [1, 3, 9]. These designs demonstrate that different structures can provide static guidance; the presence of a metal sleeve alone cannot determine the merits of a design. Sleeveless rail-guided systems differ mechanically from resin channels in which the sleeve has simply been omitted, and their results are not directly interchangeable.

Manufacturing methods may affect guide fit, height, and drilling deviation. Experimental work has examined guide type, sleeve height, drilling distance, bur diameter, and rotational speed, identifying associations between selected parameters and deviation [9]. Guiding structures, materials, and parameter combinations differ across the available studies. These findings therefore do not establish an optimal sleeve height or set of drilling parameters applicable to all systems.

6.3 Drilling Distance and Working Space

Geometrically, a longer access path produces greater target-end displacement for the same angular error. The margin for error in planning must therefore be considered in relation to the length of calcification and root thickness. Experimental findings indicate that target-end deviation may increase with drilling distance, but they do not establish a universal clinical depth threshold [9]. In posterior teeth, a straight path that appears accessible on imaging must also be achievable with the actual handpiece and bur. Open or intracoronal guidance may alleviate some space constraints, but stability, cooling, and visibility must be assessed alongside accessibility [1, 3].

6.4 Temperature Rise and Operator Factors

Drilling friction and restricted debris removal may increase temperature, particularly during continuous drilling without adequate cooling [1-2]. Available laboratory findings cannot justify dry drilling clinically or define a universal safe

duration of continuous drilling. Clinical thermal safety also depends on whether coolant reaches the cutting site, how the guide affects irrigation, intermittent operation, and root thickness. A single root surface temperature value cannot adequately characterize these conditions.

Some experiments suggest that guides can reduce differences between operators with different levels of experience, but this does not mean that the technique requires no training [5]. Clinical experience remains necessary for guide planning, assessment of guide seating, canal confirmation, and management of unexpected findings. Comparative studies can confound technique and operator effects when experience is not balanced [1, 3]. Training should therefore include not only digital design but also microscope-assisted visualization, ultrasonic canal localization, and the ability to refer complex cases.

7 LIMITATIONS AND MANAGEMENT OF FAILURE

The fixed trajectory of a static guide improves directional constraint but limits immediate intraoperative adjustments. Guidance may be insufficiently reliable when the target canal is difficult to identify on imaging, the supporting structures are unstable, or the planned path cannot be followed within the available working space. Additional CBCT imaging, scanning, planning, and manufacturing also incur time and costs. When conventional methods already permit reliable canal localization, the additional benefit of a digital workflow must be assessed in relation to case difficulty [1-3].

Failure reports show that the use of a guide does not automatically eliminate planning errors or mechanical problems. In a failed static-guided endodontic case, fixation problems and errors in manual data fusion were identified as potentially contributing factors [10]. This case does not establish that all tooth-supported guides require fixation with bone pins. More broadly, deviations can arise from guide seating, registration, manufacturing, or bur-guide mismatch, but proposed mechanisms should be separated from direct observations [1-2, 10].

From a clinical management perspective, unstable guide seating, unusual resistance, or signs of deviation should prompt reassessment of the relationship among the plan, guide, and bur. Increasing the drilling depth should not be the default corrective measure. Published failure management shows that subsequent microscope-assisted and ultrasonic canal localization or other treatments may be appropriate in particular circumstances, but the choice depends on the remaining tooth structure, perforation site, and disease status [10]. Static guides should be used as adjuncts for complex canal localization, and clinicians must retain the ability to recognize when guidance has failed and adopt another treatment approach.

8 LIMITATIONS OF THE EVIDENCE AND FUTURE RESEARCH

First, a gap remains between experimental models and clinical cases. The materials, hardness, and simulated calcification of printed teeth cannot fully reproduce natural teeth, while ex vivo models cannot fully replicate intraoral space, isolation, and patient factors. Smaller or inconsistent differences between techniques in natural-tooth experiments suggest that evaluation should move beyond establishing feasibility toward identifying the cases that derive additional benefit [1, 3]. Clinical studies should report tooth position, calcification length, previous canal localization attempts, remaining tooth structure, and operator background so that the applicability of their findings to specific patients can be assessed.

Second, key outcomes need standardized definitions and separate reporting. Successful canal localization should specify whether it means reaching the residual lumen identified on imaging, establishing a negotiable path, or enabling continued canal preparation. Perforation, deviation, and conversion to another method also require clear classification. Reports of tooth structure preservation should specify whether it is assessed as access cavity volume, cavity volume after subsequent preparation, a difference in mass, or a two-dimensional imaging measure. Timing studies should define their start and end points. Geometric accuracy cannot substitute for patient pain, healing assessed on imaging, or long-term tooth survival. Differing denominators and outcome definitions materially limit comparisons across studies [3].

Third, future research should use prospective, multicenter designs in appropriately selected patient populations and evaluate clinical outcomes and the costs of the entire digital workflow. Existing randomized trials support some canal localization and accuracy outcomes, but their sample sizes and follow-up remain insufficient to determine whether long-term tooth survival improves [6-7]. Comparative studies are also needed to guide structural design choices for posterior teeth, complex anatomy, and cases with previous deviation, rather than relying solely on successful case reports. Long-term follow-up and standardized technical reporting remain priorities [1, 3].

9 CONCLUSIONS

Static guides can transfer a three-dimensionally planned access path into clinical practice and improve the predictability of access cavity preparation and canal localization in selected cases involving calcified canals or complex pulp chamber anatomy. Their accuracy advantages are supported by laboratory studies and some clinical comparative evidence. However, the extent of improvement in tooth structure preservation, operating time, and clinical outcomes depends on case characteristics, the experience of the comparator operator, and the assessment methods. Appropriate image registration, stable guide seating, compatibility between the guiding structure and bur, and reassessment of intraoral working space and abnormal findings are important conditions for use. At present, static-guided endodontics should

serve as an adjunct for complex access cavity preparation and canal localization, with standardized clinical studies needed to establish its long-term benefits.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

INFORMED CONSENT STATEMENT

Informed consent was obtained from all subjects involved in the study.

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