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ORIGINAL ARTICLE

A comparison in the efficacy of 3D-printed guides versus traditional endodontic access: an ex-vivo study

ABSTRACT

Aim: *This ex-vivo study aimed to evaluate the accuracy and efficacy of digitally designed 3D-printed endodontic guides (3DGs) in achieving a conservative endodontic access preparation on maxillary molars compared to a traditional endodontic access (TRAD).*

Methodology: *Eighty extracted maxillary molars were divided into two groups: (1) TRAD access and (2) 3DG access. Two operators with varying levels of experience performed both approaches. Time allocated to perform each procedure was recorded. Volumetric analysis was done by comparing data from the pre- and the post-operative CBCTs.*

Results: *Both operators with the 3DG cavity access located 100% of the canals present, while the TRAD groups missed 30.76–81.81% of second mesiobuccal canals. Time required and substance loss were significantly lower in the 3DG group vs. the TRAD group.*

Conclusions: *Within the limitations of this study, the use of an endodontic 3DGs helped in preserving a significantly more dental structure in significantly less time.*

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Introduction

The first step towards the treatment and prevention of apical periodontitis is to establish access to the root canal system. The objective is not only to localize all the canals but also to remove the minimally necessary dental structure to maintain the structural stability of the crown (1). Excessive removal of dental structure during this process may lead to decreased resistance to fracture and a significant weakening of the future restoration(2,3). In addition, restricted visibility due to an incorrect access cavity preparation potentially results in missed anatomy, increased strain on instruments, inadequate disinfection and cleanse of debris and smear layer removal (4, 5).

Root fractures and missed anatomy such as untreated second mesiobuccal (MB2) canals are two major causes of failed endodontic therapy (6, 7). The reported incidence of missed canals in upper first molars ranges from 41.30% to 46.50% (8). On the other hand, the presence of MB2 canals varies from 30% to 90%, but the percentage of clinically identified MB2 canals is lower than those reported in vitro due to the presence of coronal calcifications in those canals (9-12). New technologies such as the implementation of digital dentistry and cone beam computed tomography (CBCT) helped significantly overcome these challenges (13, 14). In 2010, Clark and Khademi (1) introduced the term "conservative access cavity" (CAC) which aimed to achieve a better endodontic, restorative and prosthodontic structural preservation of dentin. This approach shifted from the traditional access cavity (TRAD), where there was an emphasis on achieving straight line access to the initial curvature of the canals or the apical part of the canal. The CAC starts from the central fossa and extends only as necessary to locate the canal orifices, preserving the pericervical dentin and part of the pulp chamber roof (15).

Recently, there have been meaningful advancements in the digital applications and 3D-printing in Endodontics. Reports on the implementation of 3D-printed guides (3DGs) to provide a CAC and to facilitate the location of root canals have been published in the last few years (15-19). However, the majority of these articles used 3D-printed replicas of anterior teeth, while a low number of studies used human molars and evaluated procedural time.

Therefore, the aim of this ex-vivo study was to evaluate the accuracy of a digitally planned 3DGs on the localization of root canals, the reduction in procedural time and the preservation of dental structure in human maxillary molars. The secondary objective was to evaluate the influence of operator experience using these approaches. To test this, the null hypothesis was that there is no significant difference in the accuracy and efficacy between these two approaches.

Material and methods

Ethical aspects

This prospective clinical study was conducted at the Faculty of Dentistry, Complutense University of Madrid. The study followed the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines (20). All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The research protocol was approved by the ethics committee of the CEIC Hospital Clínico San Carlos (Madrid, Spain) with the registration number 23/554-E.

Sample size calculation

The sample size was estimated based on a previous study (21) that compared CAC, TRAD, and point endodontic access cavities, allocating 20 extracted teeth per group. Accordingly, for the analysis with alpha (α)=0.05, a heterogeneity of 50%, and 95% statistical testing power, a total of 67 teeth were indicated as the ideal size re-

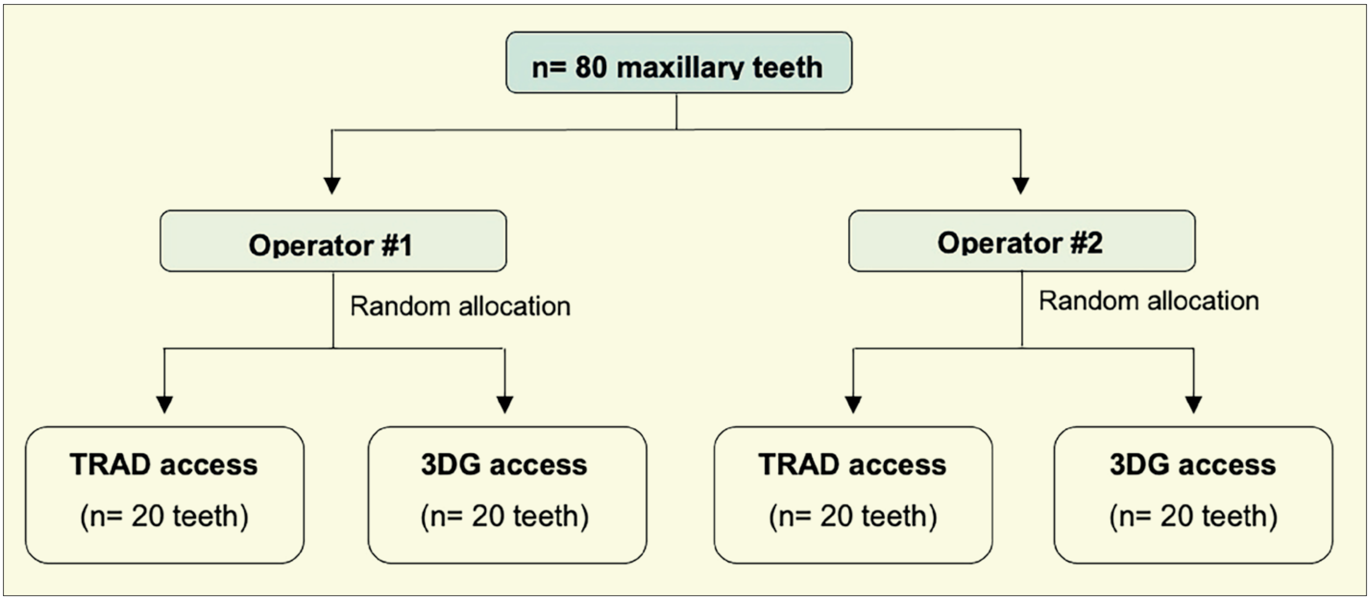

Figure 1
Study distribution (TRAD., traditional access cavity group; 3DG., 3D-printed guide access cavity group).

quired for observing significant differences. Twenty teeth were allocated for each testing group.

Study design
This experimental laboratory study was performed on extracted maxillary teeth. Eighty human maxillary first and second molars were collected from the Department of Dental Clinical Specialties at the Complutense University of Madrid, Spain. Two operators with different levels of experience in endodontic treatments performed the procedures. Operator #1 was a general dentist with over 10 years of experience, including root canal treatments in anterior teeth and premolars, and occasionally on maxillary or mandibular first molars. Operator #2 was a third-year endodontic resident with previous endodontic training. Each operator worked on 40 teeth randomly allocated in two groups: one group where a TRAD access cavity (n= 20 teeth) was performed and another group using 3DGs (20 teeth) (Figure 1) for access cavity preparation. The teeth were mounted in a human skull to mimic the anatomical structures encountered during the image acquisition. A custom-made jig using Vinyl Polysiloxane (Aquasil Easymix Putty, Dentsply Sirona, York, PA, USA) was used to replicate the pre- and post-CBCT imaging position (Figure 2).
Pre- and postoperative CBCT (pre-CBCT and post-CBCT, respectively) images were acquired to evaluate the amount of tooth structure removed during endodontic cavity access preparation. CBCT scans were taken using a 3D Accuitomo (Morita Corp., Irvine, CA, USA) with scan parameters set to 90 kVP and 7.0 mA, at a field of view of

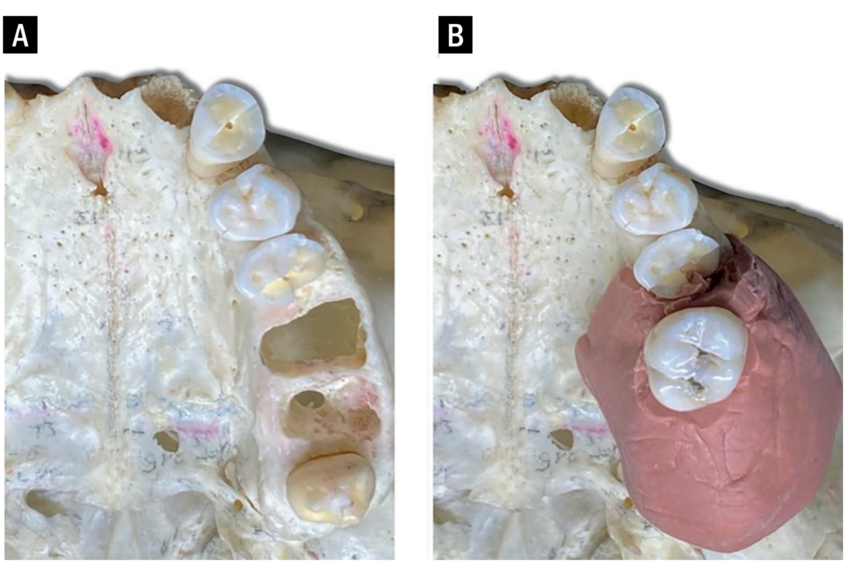

Figure 2
A) Occlusal view of the skull with the socket to receive the sample teeth. **B)** Custom made jig placed positioned in the skull.

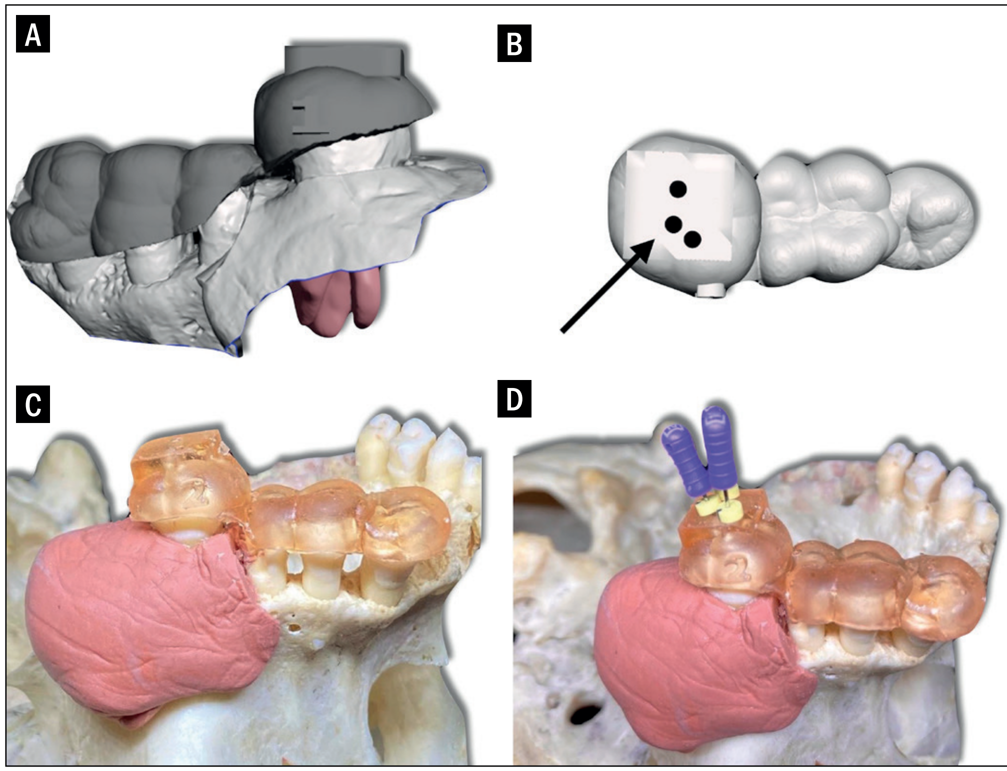

Figure 3
A) 3DG positioned on the maxillary teeth. **B)** Occlusal view of the 3DG (*black arrow indicates the 3 circular openings where canals are located). **C)** 3DG positioned in the maxillary teeth. **D)** View of #10 K-files through the circular openings demonstrating the accuracy of the 3DG.

140x100 mm at the "high resolution" setting (100 microns voxel size). The CBCT scans were not available for the operators before the access cavity procedures. Periapical radiographs were available for operative reasons as needed. The CBCT images were evaluated by a radiologist and by independent evaluator after the post-op scan was completed.

The design and fabrication of the 3DGs were carried out by an investigator not involved in the access cavity preparation. The protocol implemented for the design and printing was as follows: A digital impression of the teeth using an intraoral scanner was taken (Cerec Omnicam, Dentsply Sirona, Bensheim, Germany) to create the stereolithographic (STL) file of the anatomy of the occlusal surfaces. The digital images of the CBCT were segmented in an editor for Digital Imaging and Communication in Medicine (DICOM) files, and different STL files were created (22). One file included the anatomy of teeth and bone, and a second file presented the segmentation of teeth individually without bone tissue present. These STL files were merged in a 3D triangular mesh editor software (MeshLab, ISTI-CNR, Pisa, Italy). After the merging process, the STL files were introduced into another 3D mesh editor software (Meshmixer, Autodesk Inc., Ontario, Canada) for the final design of the digital endodontic guides based on the canal location information obtained from the CBCT images. The software used for the entire digital planning are freely accessible (Open source). The 3DG was designed so that the distance from the entrance of the canal to the circular orifice on the guide matched the length of the drill to a reference point. Then, the 3DG was printed in a 3D printer (Form2, Formlabs, Somerville, MA, USA) using a Food and Drug Administration (FDA) approved resin (Dental SG Resin, Formlabs, Somerville, MA, USA) (Figures 3 and 4).

The skull was positioned in the dental chair to mimic a clinical environment. Operators were allowed to use dental loupes (4.5x magnification) or operating microscope (0.5x magnification) as a form of magnification, according to their preferences during the cavity access procedures. Even

Figure 4
Occlusal view of one of the 3DGs used in the study showing the circular windows that correspond with each canal orifice location.

though the choice was made by each operator, Operator #1 mostly used dental loupes and Operator #2 used the operating microscope exclusively. An endodontic cassette and sodium hypochlorite 0.5% with 27-gauge needles were provided to the operators. Ultrasonic tips were also allowed to supplement the location of the canals if needed.

For the 3DG groups, the guides were positioned on the occlusal surface of the extracted teeth and their fit was carefully checked. When the proper fit was confirmed, cavity preparations were performed with a #2 round bur following the circular openings of the guides where the canal orifice will be ultimately reached. This created individual circular accesses on top of each canal orifice while the rest of the roof of the pulp chamber was untouched. Then, the 3DG was removed and the cavity access was completed using an Endo Z bur following the external outline of the orifices. In the TRAD group, standard access cavity preparation was carried out by the operators using their desired high-speed burs (#4 and 6 round burs for the initial access, and Endo Z burs to refine access cavity preparation) and ultrasonic tips as an adjunct for the localization of the canals.

Measurement of study variables

Localization of root canal orifices and procedure time

Time allocated to perform the cavity access was recorded and stopped when all canals were located and negotiated by a #10 file or if the operator decided that there is no other canal or is too calcified to negotiate.

Dental substance loss

After the access cavities were performed, a post-CBCT image was obtained for each tooth and dental substance loss analysis in mm^3 were obtained. The substance loss was defined using the following formula:

Substance loss = pre-CBCT volume – post-CBCT volume

The pre-CBCT volume was defined as the total volume of the tooth minus the pulp volume. The post-CBCT volume was defined as the coronal volume minus the preparation volume. The analysis was performed by a radiologist using CoDiagnostiX software (Dental Wings, Montreal, Canada).

Statistical Analysis

The descriptive analysis of the data was calculated using Numbers version 10.0 (6748). Data was entered manually, and statistical significance was set to an α of 0.05. T-test was performed to determine if there was any significant difference between experimental groups.

Results

Localization of root canal orifices

The two operators in the 3DG group were able to locate and negotiate all canals present in the sample teeth, including all MB2 canals. In the TRAD groups Operator #1 set of teeth had 11 MB2 present on the CBCT, from which 9 were missed (81.81%). Operator #2 set of teeth presented 13 MB2 canals, and the operator was not able to find 4 of them (30.76%). There was a statistically significant difference on the location of MB2 canals between 3DG and TRAD groups ($P<0.05$).

Procedure time

The overall mean treatment time required to perform TRAD access was 25.03 ± 5.89 min. The mean treatment time required to perform the TRAD access for Operator #1 was 30.54±2.68 min and for Operator #2 was 19.52±1.32 min ($P<0.0001$). The overall mean treatment time required to perform the 3DG access was 16.98±1.63 min. The mean treatment time required to perform the 3DG access for Operator #1 was 18.13±1.22 min and for Operator #2 was

Table 1
Treatment time required to perform the TRAD access vs. 3DG access: Comparison between operators

	TRAD Access (min)	3DG Access (min)	P-value
Operator #1	30.54±2.68	18.13±1.22	P<0.0001***
Operator #2	19.52±1.32	15.83±1.13	P<0.0001***
T-test	P<0.0001***	P<0.0001***	
Overall	25.03±5.89	16.98±1.63	P<0.0001***

**=P<0.05, **=P<0.01, ***=P<0.001.*

Table 2
Comparison of dental substance loss between the TRAD access vs. 3DG access, and between operators

	TRAD Access (mm^3)	3DG Access (mm^3)	P-value
Operator #1	251.41±18.93	121.28±12.75	P<0.0001***
Operator #2	129.45±14.41	112.03±9.54	P<0.0001***
T-test	P<0.0001***	P=0.0133***	
Overall	190.43±60.98	116.66±4.63	P<0.0001***

**=P<0.05, **=P<0.01, ***=P<0.001.*

15.83±1.13 min (*P*<0.0001). There was a significant difference in the amount of time needed to perform a cavity access when the TRAD access was compared to the 3DG access method (*P*<0.0001) (Table 1).

Dental substance loss
The overall mean access volume loss for the TRAD access was 190.43±60.98 mm^3. The mean access volume loss for the TRAD access for Operator #1 was 251.41±18.93 mm^3 and for Operator #2 was 129.45±14.41 mm^3 (*P*<0.0001). The overall mean access volume loss for the 3DG access was 116.66±4.63 mm^3. The mean access volume loss for the 3DG access for Operator #1 was 121.28±12.75 mm^3 and for Operator #2 was 112.03±9.54 mm^3 (*P*=0.0133). The T-test determined that the substance loss in the 3DG group was significantly reduced compared to the TRAD group (*P*<0.0001) (Table 2).

Discussion

The results of the present study showed that endodontic access using a 3DG presents a significant reduction in substance loss, decreased operating time, and improved MB2 location rates.
The location of the MB2 canals was greatly improved with the use of 3DGs. In this sense, Operator #1 localized a lower number of MB2 canals compared to Operator #2 (81.81% vs. 30.76%, respectively; *P*<0.05). Both operators used magnification (loupes or dental operative microscope). The presence of MB2 was determined by the preoperative CBCT, but this information was not shown to the Operators pre-operatively. Studies on methods to aid in the location of MB2 found that magnification greatly improves the detection of the MB2 (23, 24). Other studies showed that even though magnification improves the frequency of MB2 canal location, there is no significant differences between the use of loupes vs. microscope (25). Another factor that might have contributed to the differences on the location rates of MB2 between operators could be the previous experience in Endodontics of Operator #2 and the use of ultrasonic tips during the search of the MB2 (26).
The use of the CBCT volume data is a useful tool to determine the amount of dental structure preserved before and after inter-

ventions with minimal deviation (27). The present study showed a significant difference in the overall dental structure loss during the cavity access between TRAD access and 3DG access (190.43±60.98 mm^3 vs 116.66±4.63 mm^3, respectively; $P<0.0001$). Our results are in accordance with the study by Connert et al. (28) showing a significant difference in substance loss between the 3DG group vs. the TRAD group in anterior teeth. Similarly, an ex-vivo study conducted by Loureiro et al. (29) found that the 3DG access significantly reduced the dental structure loss compared with the TRAD group in extracted upper molars. However, there was no difference between these groups when evaluating mandibular incisors. The preservation of the dental structure is known to positively impact the long-term fracture resistance of endodontically accessed teeth (30, 31).

To ensure the efficiency of the procedure and patients' comfort in root canal treatment, a reduction of procedural time is beneficial. The results in our study show that there is a significant improvement in overall time needed to perform an access cavity when using 3DGs compared to the TRAD group, which saved an average of 8.05 min in procedural time ($P<0.0001$). These results are in accordance with a previous study which showed a reduction in procedural time of 10.50 min when 3DGs were used compared with a "free-hand" group (28). Our study did not take into account the additional time required for scanning the anatomy of the patient, the computer design and the fabrication of the 3DGs. Nevertheless, this additional planning time could be justified by the overall reduction in procedural time, preservation of dentin and location of canal orifices. On the other hand, 3DGs have been proven useful to aid in the location of calcified canals. Several case reports showed successful results in maxillary (29, 32-35) and mandibular incisors, (35), maxillary premolars (37), and maxillary, (37, 38) and mandibular molars (39).

The majority of the studies available in the literature have used software exclusive for dental implant planning. This is done by simulating an implant placement on a root canal and changing the parameters of the implant to match the diameter and length needed for the burs and sleeves used. In addition, most software, if not all, are subscription-based or require a one-time payment. In the present study, the entire digital workflow for the guide design used open-source software, freely accessible for any clinician.

Some of these software (Meshmixer and Meshlab) are focused on 3D editing in general, therefore, there are more possibilities at hand in terms of the design of the 3DGs. However, it should be noted that these software do not present specific dental settings or digital dental tools, therefore they are not as user-friendly as the dental software programs.

Despite the above-mentioned advantages, the use of 3DGs for endodontic treatments presents multiple limitations. First, 3DGs are not suitable for emergency scenarios due to pain or infection when the tooth in question requires immediate treatment. Designing and printing these guides takes a significant amount of time and are only indicated for cases when the patient will be seen on a different date after the initial consult. In addition, CBCT imaging is essential for it, however, radiographic artifacts might compromise the accuracy of the data and could negatively influence the superimposition of the DICOM files with the surface scans files from the intraoral scanner. This is due to the beam hardening artifacts created by dental implants and/or metallic restorations such as full-coverage crowns (40, 41). Nevertheless, there are techniques available that facilitate the superimposition of the images by adding fiducial markers in both the CBCT and intraoral scan when metallic restorations are present (42).

Furthermore, in cases where calcified canals are present, 3DGs cannot reach past a curvature because the drill or bur is limited to an apico-coronal motion. If the canal presents a curvature before the target point, the use of these guides should be avoided to prevent the risk of perforation. Also, clinicians need to take into consideration that the thickness of the guide and the sleeve height reduces the inter-occlusal space available for the instruments. In posterior cases with limited mouth opening, the use of 3DGs would not be feasible. Nevertheless, the use of a sleeveless guide would help to reduce the vertical space occupied by the guide (33). In addition, conservative access cavities performed using the 3DGs could result in the accumulation of debris in the potential undercuts of the roof of the pulp chamber, which might serve as a source of a persistent infection (43).

This study also presents limitations. The dental substance loss analysis was performed using CBCT imaging. Even though this type of imaging is acceptable for this type of evaluation, a Micro-CT analysis would have provided more accurate data when the pre- and postoperative scans were taken. Also, the patients' age from the extracted teeth used in the sample could not be determined. This can significantly affect the difficulty of canal localization and negotiation in different age groups. Older teeth usually present narrower pulp chambers and higher prevalence of calcified canals, increasing the difficulty of the access cavity and location of the canals. Our study demonstrated significant differences in the accuracy and efficacy of achieving conservative endodontic access preparation on maxillary molars between the digitally designed 3D-printed endodontic guides (3DGs) and traditional endodontic access (TRAD). Therefore, we reject the null hypothesis that there is no significant difference between these two techniques.

These findings suggest that 3D-printed endodontic guides may offer a more effective alternative to traditional methods for achieving conservative access in endodontic procedures. Further studies are needed to evaluate the feasibility of these guides in clinical practice. In addition, the current digital workflow is convoluted for routine use. Newer and more user-friendly digital workflows need to be investigated to broaden the use of the 3DGs in Endodontics.

Conclusion

Within the limitations of this ex-vivo study, the use of 3DGs leads to significant reductions in the amount of tooth structure removed and procedural time when performing endodontic access cavities, regardless of the operator's experience. In addition, the use of these guides shows significantly better location rates of the MB2 canal compared to a non-guided approach.

Clinical Relevance

The use of 3DGs leads to a significant reduction in the amount of tooth structure removed and procedural time when performing endodontic access cavities, independently from the experience of the operator.

Conflict of Interest

The authors deny any conflicts of interest related to this study.

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