Guided Endodontics versus Conventional Access Cavity Preparation: A Comparative Study on Substance Loss Using 3-dimensional–printed Teeth

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Abstract

Introduction: The aim of this *in vitro* study was to compare endodontic access cavities in teeth with calcified root canals prepared with the conventional technique and a guided endodontics approach regarding the detection of root canals, substance loss, and treatment duration. **Methods:** Six identical sets of upper and lower jaw models were produced with 3-dimensional–printed incisors that had simulated calcified root canals. Splints for guided access preparations were fabricated based on 3-dimensional surface scans and cone-beam computed tomographic data sets. Under simulated clinical conditions, 3 operators with different levels of experience prepared access cavities on each front tooth with the conventional technique and guided endodontics (8 teeth per technique and operator). Access cavities were volumetrically assessed on postoperative cone-beam computed tomographic scans. Statistical significance was tested by examining the overlap of 95% confidence intervals (CIs). **Results:** Canal location was successful in 10 of 24 cases (41.7%) using the conventional technique and 22 of 24 cases (91.7%) with the guided approach. The mean substance loss of the conventional access and the guided access was 49.9 mm^3 (95% CI, 42.2–57.6 mm^3) and 9.8 mm^3 (95% CI, 6.8–12.9 mm^3), respectively. The treatment lasted 21.8 minutes (95% CI, 15.9–27.7 minutes) for the conventional technique and 11.3 minutes (95% CI, 6.7–15.9 minutes) for guided endodontics. The success of the guided approach was not influenced by the experience of the operator. **Conclusions:** Guided endodontics allows a more predictable and expeditious location and negotiation of calcified root canals with significantly less substance loss. *(J Endod 2019;45:327–331)*

Key Words

3-dimensional–printed teeth, guided endodontics, printed templates, pulp canal calcification, root canal treatment, substance loss

Significance

Endodontic treatment of teeth with pulp canal calcifications is challenging and may be associated with a high loss of dental hard tissue. "Guided endodontics" provides a highly accurate technique for the preparation of minimally invasive access cavities.

Endodontic access to calcified root canals is a challenging task. It is prone to technical failures including alterations of the root canal geometry and substantial loss of dental hard tissue, which may weaken a tooth considerably or result in root perforation (1).

"Guided endodontics," a novel guided approach for the preparation of apically extended access cavities, was introduced to overcome such complications (2–5).Miniaturization of conventional instruments has made this technique implementable even for teeth with narrow roots such as mandibular incisors (6, 7). This technique proved to be accurate, expeditious, and operator independent in *in vitro* settings (2, 6). Although clinical treatment trials are missing, recent clinical case reports show the successful application of this technique in endodontic practice (3, 7, 8).

However, there is a paucity of comparative evidence regarding root canal location in calcified teeth through conventional and guided approaches. The aim of the present *in vitro* study was to compare the conventional technique with the guided approach for root canal location in 3-dimensional (3D)-printed teeth with simulated calcified root canals regarding:

1. the detection and negotiation of root canals,
2. the amount of substance loss, and
3. treatment duration. Second, the influence of the operator's experience was assessed for both techniques.

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Materials and Methods

Study Model

Ethical approval was obtained from the local research ethics committee (EKNZ UBE-15/111). Micro–computed tomographic imaging of 1 extracted sound upper central incisor, 1 lower central incisor, and an upper lateral incisor was performed (Inveon Multimodality Single Photon Emission CT Scanner; Siemens Preclinical Solutions, Knoxville, TN) with a voxel size of 27 μm. Inveon Acquisition Workplace software V1.4.3.6 (Siemens Preclinical Solutions) was used for image capturing and reconstruction. All teeth had 1 root with a single root canal. Obtained Digital Imaging and Communications in Medicine (DICOM) files were uploaded to the free ITK-SNAP software (Version 3.6, http://www.itksnap.org). A suitable threshold was selected by an experienced operator; files were segmented and exported as Standard Tessellation Language (STL) files. STL files were imported to the free Blender software (Version 2.78, www.blender.org). The root canals of all teeth were digitally modified so that the orifice of the root canal was at a distance of 5 mm from the apex, and the root canal diameter was set to 0.2 mm. Each tooth was mirrored along the longitudinal axis to obtain teeth for each quadrant. Modified STL files were checked with Netfabb (Version 14.0.23.0l Autodesk, San Rafael, CA) for printability and sent to a 3D printer for production (Objet Eden 500V, material: med 690; Stratasys Ltd, Minneapolis, MN).

Six identical sets of upper and lower jaw models were produced with printed central and lateral incisors. For stability reasons, plastic teeth (ANA-4 Z; Frasaco GmbH, Tettnang, Germany) were used as substitutes for canines and first and second premolars in each quadrant.

The cervical area of each tooth was connected with an approximately 2-mm-thick layer of cold-curing polymer (ProBase; Ivoclar Vivadent AG, Schaan, Liechtenstein) without covering the root surface to facilitate cone-beam computed tomographic (CBCT) imaging. A removable base for the model was produced using a putty silicone (Fifty-Fifty 95 putty; Klasse 4 Dental GmbH, Augsburg, Germany) to ensure stability during clinical procedures (Fig. 1).

Six models (3 upper and 3 lower jaws) were assigned to the guided endodontics group; the other 6 were for conventional access cavity preparation. For each model, a preoperative CBCT scan with a voxel size of 125 μm was performed (Morita Accuitomo 80; J Morita Manufacturing Corp, Kyoto, Japan) and stored as a DICOM file. In addition, STL files were created through a 3D intraoral scanner (Dental Wings Intraoral Scanner; Dental Wings Inc, Montreal, Canada).

Virtual Planning of Guided Endodontics

The virtual planning for the 6 models of the guided endodontics group was performed according to Connert et al (6, 7). In brief, STL and DICOM data were uploaded to coDiagnostiX software (Version 9.2, Dental Wings Inc), and both scans were matched by aligning the contours of the teeth. The virtual image of a bur with a diameter of 0.85 mm (Gebr Brasseler GmbH & Co KG, Lemgo, Germany) was superimposed to the data set to access the orifice of the root canal. The position was checked in every 3D aspect. Afterward, a virtual sleeve with an inner diameter of 0.88 mm was placed. The template was designed and 3D printed (Objet Eden260 V, material: MED610; Stratasys Ltd). Custom metallic sleeves (steco-system-technik GmbH & Co KG, Hamburg, Germany) were integrated into the final template.

Access Cavity Preparation

Three dentists with normal visual acuity were tasked to prepare coronal access cavities on each front tooth of an upper and a lower jaw model with the conventional technique and the guided endodontics technique (4 models/16 teeth per operator, 8 teeth per technique and operator).

Operator 1 was a certified specialist in endodontics with 9 years of professional experience, operator 2 was a general dentist with 3 years of professional experience, and operator 3 was a new dental school graduate. The models were mounted in a dental mannequin (P-6; Frasaco GmbH, Tettnang, Germany) fixed on a dental chair (Teneo; Dentsply Sirona, York, PA) to mimic a clinical situation.

CBCT scans and digital periapical radiographs were available for both techniques during the whole treatment as diagnostic images. Operators were allowed to use dental loupes as well as an operating microscope for both techniques (Pro Ergo; Carl Zeiss AG, Oberkochen, Germany).

For initial conventional access cavity preparation, a high-speed contra-angle handpiece (1:5, KaVo Master Series; KaVo Dental GmbH, Biberach, Germany) with a cylindrical diamond bur with rounded edges (837 KR; Intensiv SA, Montagnola, Switzerland) was used. To locate the root canal, operators were allowed to additionally use long pulp burs ("Müller" bur, Gebr Brasseler GmbH & Co KG) and/or an ultrasonic device (P Max Newtron XS; Acteon, Düsseldorf, Germany) with a size 25 IRRI K file (VDW GmbH, Munich, Germany). Because of the reduced hardness and burn resistance of the resin material compared with dentin, the ultrasonic instruments in particular had to be applied with care and in intermittent intervals. If the operators were unable to access a root canal or deemed the tooth too compromised to be retained (because of perforations), they were allowed to stop the treatment.

For the guided endodontics approach, operators obtained a short introduction into the technique and the virtual planning. They received

Figure 1. Study models with 3D-printed incisors with (*left*) unembedded roots for radiographic imaging and (*right*) embedded roots for clinical procedures.

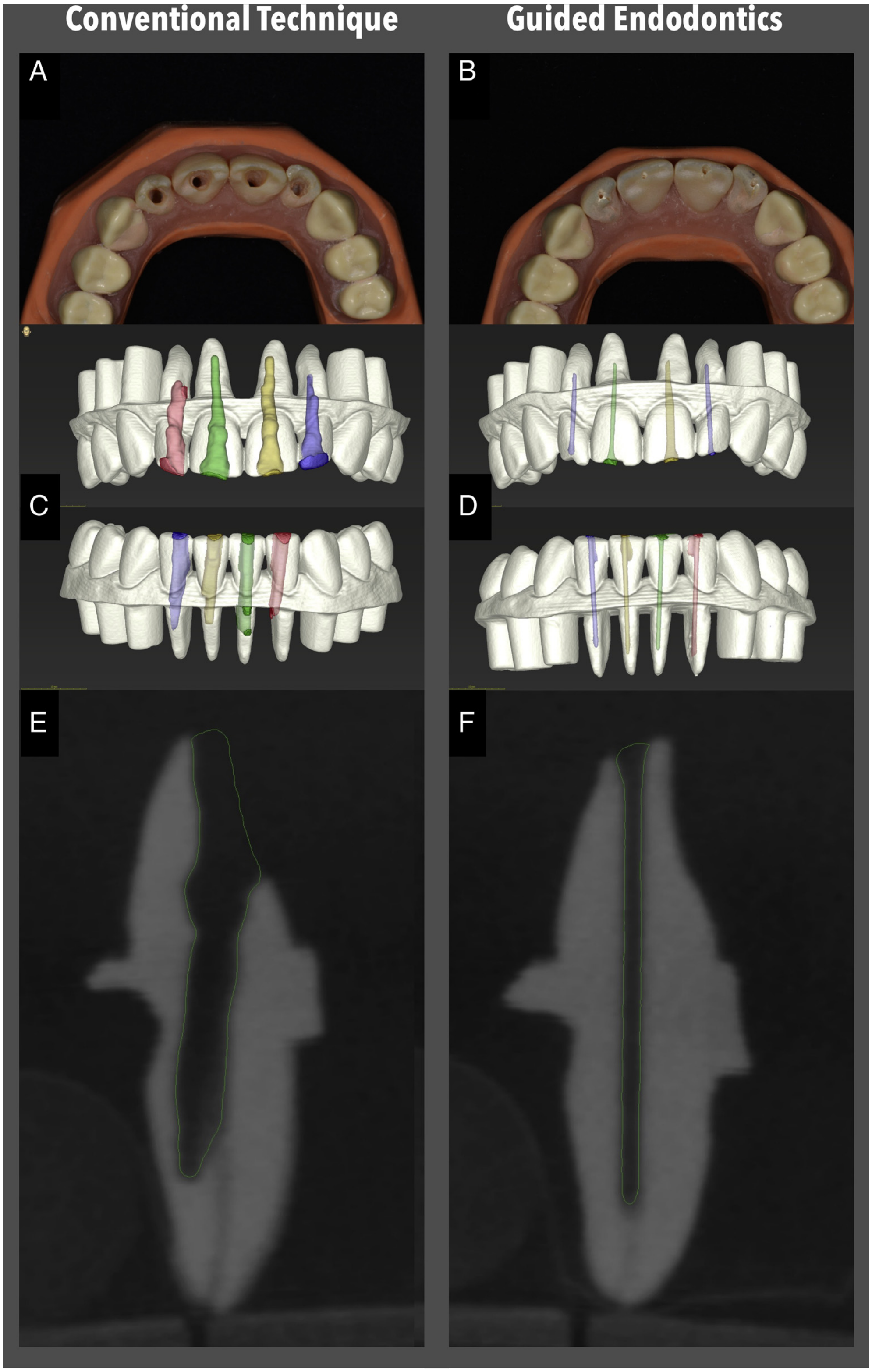

Figure 2. A comparison of the (*left column*) conventional technique and (*right column*) guided endodontics. (*A* and *B*) Examples of upper jaw models after access cavity preparation, (*C* and *D*) visualization of access cavities, and (*E* and *F*) the sagittal plane of a postoperative CBCT scan showing a lower incisor.

the printed template with the corresponding bur. Clinical procedures were performed according to Connert et al (6, 7). If the root canal was accessed and negotiated, a periapical radiograph was performed with a K-file to verify the result of the treatment.

Time was recorded from the start of the treatment until the root canal was accessed and negotiated or the operator stopped the (unsuccessful) treatment. A postoperative CBCT scan was performed of all models. The built-in tools of coDiagnostiX software

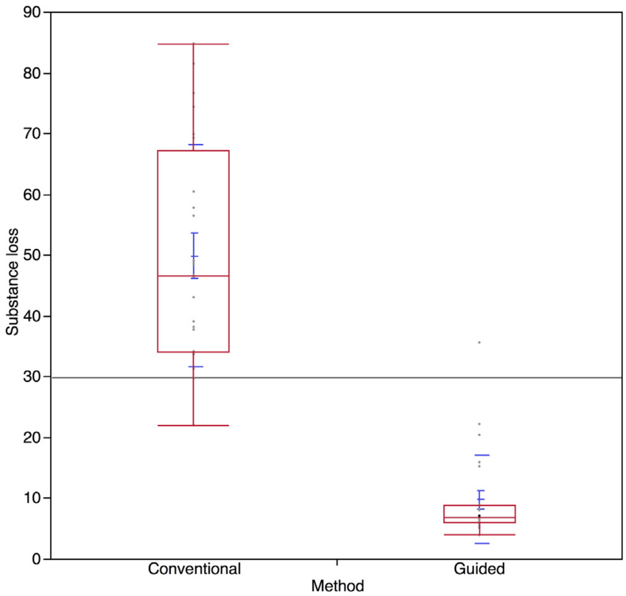

Figure 3. The overall substance loss (mm^3) of the conventional technique and guided endodontics.

were used to mark the access cavity and calculate the volume in mm^3 (Fig. 2*A–F*).

Statistical Analysis

A descriptive analysis regarding successful detection of root canals, substance loss, and treatment duration was performed for each operator and method. Statistically significant differences were expressed by nonoverlapping 95% confidence intervals (CIs). Statistical analyses were conducted with JMP 11 (SAS Institute Inc, Cary, NC).

Results

The mean substance loss for all 3 operators using the conventional technique was 49.9 mm^3 (95% CI, 42.2–57.6 mm^3), and for the guided approach, it was 9.8 mm^3 (95% CI, 6.8–12.9 mm^3) (Fig. 3).

The mean treatment duration was 21.8 minutes (95% CI, 15.9–27.7 minutes) for the conventional technique and 11.3 minutes (95% CI, 6.7–15.9 minutes) for guided endodontics.

Using the conventional technique, 10 of 24 root canals were accessed and negotiated (41.7%). Location and negotiation using guided endodontics were achieved in 22 of 24 root canals (91.7%). Table 1 shows the results divided by operators regarding successful location and negotiation of canals, substance loss, and treatment duration for both methods.

Discussion

This is the first study comparing root canal location and dentin loss between conventional and guided access cavity preparations in 3D-printed teeth with simulated calcified root canals. The results show that the guided technique outperforms the conventional approach in each of the investigated aspects.

Location and negotiation of calcified root canals are usually possible when the treatment is performed under an operating microscope by a specialist (9). However, data on the substance loss associated with root canal location in such teeth are scarce. The access cavities resulting from the guided endodontics approach in our study conserved as much tooth substance as possible. They are comparable with the constricted endodontic cavities recently reported in the literature. Such minimally invasive access cavities conveyed a benefit of increased fracture resistance in some studies (10, 11), whereas no effect was detected in other investigations (12, 13). In teeth with calcified root canals, as simulated in the present investigation, the attempt to locate root canals through a traditional approach is likely to result in higher substance loss compared with noncalcified teeth in which locating root canals is more straightforward. Thus, biomechanical benefits of tooth substance preservation through a guided access preparation might be greater than in the aforementioned studies.

In a previous clinical investigation on technical failures during the treatment of calcified teeth, perforations of the root, file fractures, and unsuccessful canal negotiations were considered as technical failures, whereas the amount of unnecessary substance loss was not taken into account (1). The amount of hard tissue loss in a buccolingual extension can hardly be assessed on 2-dimensional radiographs. Yet, such substance losses may be relevant in terms of a reduced fracture resistance of teeth. Finite element simulations of root canal–treated teeth suggest that the buccal cervical area represents the region most at risk for fracture (14).

The loss of hard tissue resulting from the guided approach may be comparable with post space preparation and leads to concentric substance loss around the calcified root canal. Substance loss and modifications of the natural root canal geometry associated with post space preparation significantly affect the biomechanical behavior of teeth (15, 16). However, dentin losses resulting from the attempt to conventionally locate calcified root canals can occur in any direction and lead to an unpredictable destruction of the root. Thus, the conventional approach is more likely to have even more detrimental impacts on the inner tooth morphology, deformability, and fracture strength. Against that background and considering the rather small diameter of the bur, apically extended access cavity preparations through guided endodontics may entail clear advantages for the structural stability of treated teeth.

Some limitations of the guided endodontics approach including the need for a straight path to the apical target point, limited accessibility in the posterior area, and possibly dentinal microcrack formation and temperature increase were previously discussed (2, 3, 6, 7).

TABLE 1. The Results of Each Operator (Unexperienced/Experienced/Specialist) for the Conventional Technique and Guided Endodontics Regarding the Detection of Root Canals, Substance Loss, and Treatment Duration

	Conventional technique			Guided endodontics		
Operator	Detected canals	Substance loss (95% CI) (mm^3)	Treatment duration (95% CI) (min)	Detected canals	Substance loss (95% CI) (mm^3)	Treatment duration (95% CI) (min)
1-unexperienced	0/8	33.8 (27.3–40.4)	13.8 (5.9–21.8)	8/8	7.0 (6.1–7.9)	7.6 (5.4–9.8)
2-experienced	4/8	60.0 (48.6–71.5)	29.8 (15.9–43.8)	7/8	15.4 (6.7–24.1)	18.9 (5.9–32)
3-specialist	6/8	55.8 (39.3–72.3)	21.7 (12.2–31.2)	7/8	7.1 (6.1–10.1)	7.5 (1.9–13.1)

CI, confidence interval.

Additionally, in a clinical situation, CBCT artifacts resulting from highly radiopaque restorations may hamper the alignment of the scans.

In the present study, 3D-printed teeth were used to obtain a high level of standardization that ensured comparability between traditional and guided access preparations. However, the use of 3D-printed teeth has some inherent drawbacks that must be taken into consideration. Because 3D-printed teeth consist of only 1 material, without any regional variation in color or consistency, anatomic landmarks that may guide the clinician during traditional canal location in natural teeth are absent. Furthermore, in clinical situations, calcified root canals may be negotiable more coronally than at the point where the root canal is detectable on the radiograph. Thus, the use of 3D-printed teeth in the present study might have placed the conventional technique at a slight disadvantage.

Guided endodontics yielded favorable results in each investigated aspect in the present study, which suggests that, even for endodontic specialists with operating microscopes, this guided approach outperforms conventional root canal location in calcified teeth. The proportion of successful root canal location and negotiation with the guided technique (22/24) was significantly higher compared with the conventional technique (10/24) in the present study. However, the guided technique was not invariably successful. This is in contradiction to previous studies in which all root canals were detected when the guided endodontics technique was applied (2, 3, 6, 7). In contrast to those studies, the teeth were not fully embedded in resin in the present study. Sufficient discrimination between artificial teeth and artificial bone was a requisite feature for the guided treatment planning in the present study. Because of comparable radiopacities of the 3D-printed teeth and the embedding resin, the apical two thirds of the roots were left unembedded; they were covered with a removable silicone base during the clinical procedure. Because the stiff embedding material only surrounded the cervical tooth region, slight mobility of the teeth was unavoidable. This might have been a source of inaccuracy. Furthermore, unsuccessful treatments occurred in upper lateral incisors. These teeth had very thin roots and a pronounced curvature at the transition between the apical and middle third of the root. Thus, even an optimal access cavity without any deviation would have led to considerably reduced remaining dentin thickness of the canal wall in the danger zone at the apical target point of the preparation. Consequently, minimal deviation could have led to perforations in these teeth.

In conclusion, within the limitations of this *in vitro* study, the guided endodontics access leads to a more predictable and expeditious location of calcified root canals with significantly less substance loss compared with the traditional endodontic access. Moreover, in contrast to traditional access preparations, the success of the guided approach is not influenced by the experience of the operator.

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

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