BASIC RESEARCH – TECHNOLOGY

# Dynamically Navigated versus Freehand Access Cavity Preparation: A Comparative Study on Substance Loss Using Simulated Calcified Canals

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## ABSTRACT

**Introduction:** The aim of this *in vitro* study was to compare the speed, qualitative precision, and quantitative loss of tooth structure with freehand and dynamically navigated access preparation techniques for root canal location in 3-dimensional–printed teeth with simulated calcified root canals. **Methods:** Forty maxillary and mandibular central incisors (tooth #9 and tooth #25) were 3-dimensionally printed to simulate canal calcification. Under simulated clinical conditions, access preparations were randomly performed with contemporary free-hand and dynamically navigated techniques. Qualitative precision and quantitative loss of tooth structure were assessed on postoperative cone-beam computed tomographic scans using ITK-SNAP open-source segmentation (http://www.itksnap.org/). The associations between jaw, technique, volume of substance loss, and operating time were determined using analysis of variance models with Tukey-adjusted post hoc pair-wise comparisons. The kappa statistic was used to determine agreement between 2 independent, blinded raters on the qualitative assessment of the drill path. The association between the technique and jaw and qualitative assessment scoring was compared using the Fisher exact test. The significance level was set at .05. **Results:** Dynamically navigated accesses resulted in significantly less mean substance loss in comparison with the freehand technique (27.2 vs 40.7 $mm^3$, $P < .05$). Dynamically navigated accesses were also associated with higher optimal precision (drill path centered) to locate calcified canals in comparison with the freehand technique (75% vs 45%, $P > .05$). Mandibular teeth were associated with a negligible difference in substance loss between the access techniques (19.0 vs 19.1 $mm^3$, $P > .05$). However, qualitatively the freehand technique was still prone to 30% higher chance of suboptimal precision (drill path tangentially transported) in locating calcified canals. Overall, dynamically navigated accesses were prepared significantly faster than freehand preparations (2.2 vs 7.06 minutes, $P < .05$). **Conclusions:** Within the limitations of this *in vitro* study, overall dynamically navigated access preparations led to significantly less mean substance loss with optimal and efficient precision in locating simulated anterior calcified root canals in comparison with freehand access preparations. *(J Endod 2020;■:1–7.)*

## KEY WORDS

Access cavity; calcified canals; dynamic navigation; guided endodontics; Navident; segmentation

## SIGNIFICANCE

Dynamically navigated access preparations can minimize the loss of tooth structure with optimal and efficient precision in locating simulated anterior calcified root canals. A contemporary incisal access approach with the freehand access technique may be beneficial in preserving pericervical dentin in mandibular incisors.

Pulp canal calcification or obliteration commonly occurs as a result of trauma, caries, placement of restorations, vital pulp therapy procedures, orthodontic treatment, aging, and systemic intake of statins[1–4]. Endodontic treatment of teeth with pulp canal obliteration is categorized as a "high" difficulty level according to the American Association of Endodontists, mainly because of challenges with the access opening[5].

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Clinical studies have reported 20%–71% success in locating posttraumatically obliterated canals[6,7]. The use of cone-beam computed tomographic (CBCT) imaging enables more accurate treatment planning; however, the conventional access opening approach to locate the canals may lead to aggressive loss of sound dentin and increased risk of iatrogenic errors, thereby reducing the long-term prognosis[8–10].

The advancements in surface scanning and 3-dimensional (3D) printing technology have led to the development of static guidance systems that transfer predetermined access drill path information from the patient's CBCT image to rigid templates or guides[11,12]. Reports on errors accumulated at each step of the digital workflow for fabricating static guides have questioned its accuracy in the implant literature[13,14]. Its widespread use in endodontics has been limited mainly because of the additional time and cost involved with intraoral scanning and 3D printing to fabricate the static guide[12,15]. Static-guided access cavity preparation has been reported to cause peripheral/tangential deflection from the original canal orifice in about 60% of clinical cases, which may be attributed to the inability to change the predetermined drill position[16].

The introduction of optically driven dynamic navigation systems in implant dentistry offers the potential to overcome the limitations of static-guided systems by enabling real-time visualization of the position and angulation of the implant drills[17]. Most studies using dynamic navigation for implant placement used the first-generation navigation system, which requires additional CBCT scans with thermoplastic stents and radiographic fiducial markers[17–19]. The cost, time, and error considerations associated with thermoplastic stent fabrication make this early system clinically unsuitable for endodontic procedures. The introduction of recently developed technology referred to as "trace registration" has eliminated the need for a thermoplastic stent for implant placement with dynamic navigation[20]. This updated second-generation navigation technology with trace registration can perform real-time registration mapping between the patient's oral structures and preexisting small field view of CBCT scans, thereby reducing chairside time and radiation exposure.

A novel "dynamically navigated" endodontic access technique with high-speed drills and trace registration has recently been proposed by Jain et al, to accurately locate highly difficult calcified canals through minimally invasive access cavities[21]. However, there is a scarcity of comparative evidence regarding the performance of contemporary freehand techniques and the use of dynamic navigation for access cavity preparation in locating calcified canals. The aim of this *in vitro* study was to compare the speed, qualitative precision, and quantitative loss of tooth structure with freehand and dynamically navigated access preparation techniques for root canal location 3D-printed teeth with simulated calcified root canals.

## MATERIALS AND METHODS

Anatomically precise maxillary and mandibular single-rooted central incisors ($n = 40$) were custom 3D printed (TrueTooth; DELabs, Santa Barbara, CA) to simulate pulp canal obliteration. The distance from the incisal edge to the canal space in the maxillary (tooth #9) and mandibular incisor (tooth #25) measured approximately 16.0 and 13.0 mm, respectively (Fig. 1*A* and *B*). The experimental teeth were individually mounted according to their anatomic position in a maxillary or mandibular ModuPRO Endo model (Acadental, Overland Park, KS) to simulate a partially dentate jaw. All the teeth were mounted using a puttylike material (Splash! Putty; DenMat, Lompoc, CA). A block randomization schedule was generated using SAS EG v6.1 software (Opsware Inc, Sunnyvale, CA) to equally distribute all samples based on the jaw type and the access preparation technique. Experiments were conducted over a period of 4 months with at least 1 week between each treatment session to decrease the operator's familiarity to the tooth anatomy, canal location, and orientation during a treatment session. A second-year endodontic resident (M.W.S.) performed the access, canal identification, and verification.

A latex face with a limited mouth opening was used to cover the jaw model setup to simulate limited visibility and pressure due to facial soft tissues. Teeth were isolated using a dental dam. The following burs were available for use with a high-speed handpiece for freehand and dynamic access preparations: a surgical length #2 round bur (Coltene, Altstätten, Switzerland), an 859 FGSL bur (Komet USA, Rock Hill, SC), and an EndoZ bur (Dentsply Sirona, York, PA). Limited field of view CBCT scans taken with the CS 8100 3-D unit (Carestream Health Inc, Rochester, NY) were obtained for all mounted treatment teeth with the following exposure parameters: a 60-kV peak, 2.0 mA, 15.0 seconds, and a 75-μm voxel size.

### Freehand Access Cavity Preparation

Limited field of view CBCT scans were available to view during the freehand access procedures to aid in assessing angulation and measurements. The design for preparations in both maxillary and mandibular incisors started away from the cingulum and extended toward the incisal edge. The accesses were performed under a dental operating microscope (Global Surgical Corporation, St Louis, MO)[22]. The time of each access preparation was recorded from the initial preparation of the tooth structure to the point of successful canal negotiation or when the operator suspected the access depth to reach the estimated measurement to the canal space.

### Dynamic Navigation Access Cavity Preparation

Access cavities were made under full guidance of the second-generation Navident (ClaroNav, Toronto, Ontario, Canada) workflow (ie, scanning, planning, tracing, and placing [dynamically navigated access]) as described by Jain et al[21]. The time of each access preparation treatment was recorded (Apple Inc, Cupertino, CA) to the point at which the bur reached the end of the planned drill path.

A periapical radiograph of the tooth with a #15 K-file (Dentsply Sirona) within the access/canal confirmed successful canal location. In case of a suspected perforation or inability to access the canal in any group or under any circumstance, the operator was allowed to stop the treatment.

Substance loss was quantified using postoperative CBCT scans that were analyzed with the ITK-SNAP DICOM viewer (http://www.itksnap.org/), an open-source medical image computing platform for biomedical research. It enables semiautomatic segmentation of the plastic tooth structure in the foreground, whereas lower threshold values can be used to exclude the prepared canal in the background. Automatic active contour evolution by ITK-SNAP helps analyze the volume of the substance loss and prepare 3D rendering models of the prepared tooth. Additionally, 2 board-certified endodontists independently and blindly analyzed the models for qualitative assessment of the access cavity preparation. The completed access drill paths were classified as 1 of the following:

1. Optimal precision: a centrally located drill path in relation to the root canal with location and negotiation of the root canals possible (Fig. 1*E* and *F*)
2. Suboptimal precision: a peripheral or tangentially transported drill path in relation to the root canal with location and negotiation of the root canals possible (Fig. 1*C* and *D*)

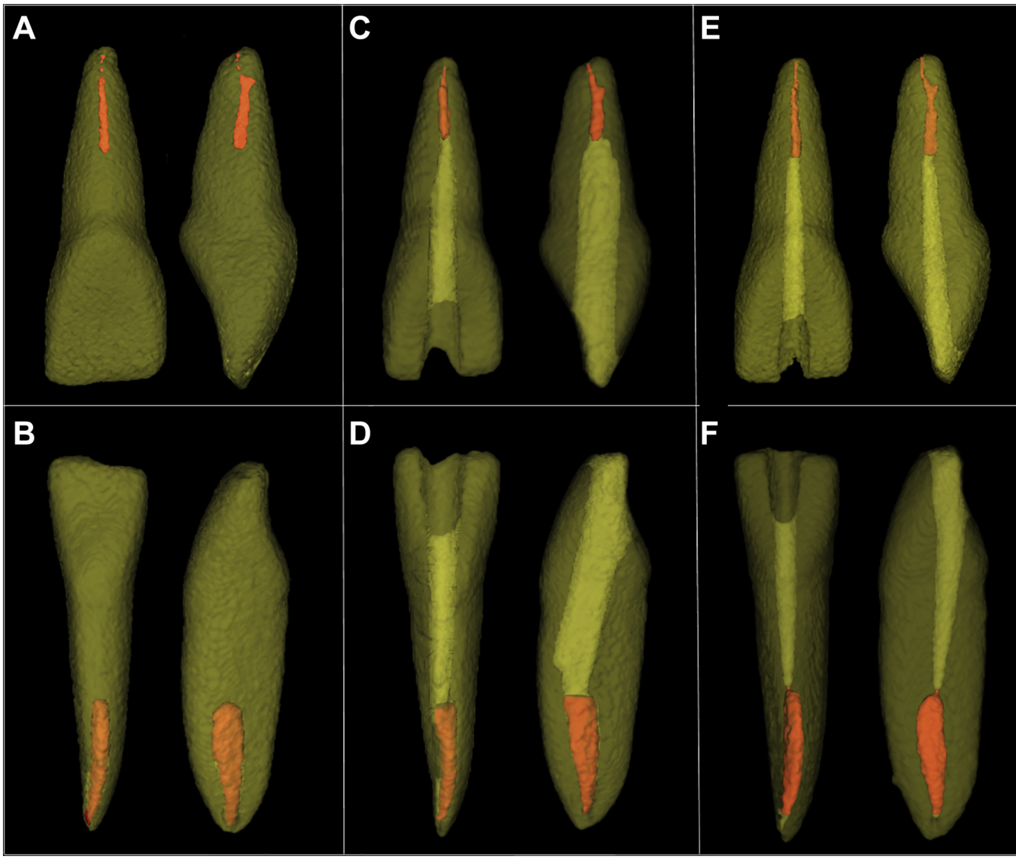


**FIGURE 1 –** Digital 3D rendering illustrations of freehand access versus dynamically navigated access cavity preparation. Preoperative 3D renderings of the 3D-printed (*A*) maxillary and (*B*) mandibular incisors preoperatively from facial and mesial views simulating calcified anatomy. (*A* and *B*) The *orange color* represents the pulp canal space. Representative postoperative 3D renderings of (*C*) maxillary and (*D*) mandibular incisors from facial and mesial views after freehand access preparation depicting qualitative classification of **suboptimal precision** (ie, a peripheral or tangentially transported drill path in relation to the root canal; with the location and negotiation of root canal space). Representative postoperative 3D renderings of (*E*) maxillary and (*F*) mandibular incisors from facial and mesial views after dynamically navigated access preparation depicting qualitative classification of **optimal precision** (ie, a centrally located drill path in relation to the root canal; with the location and negotiation of root canal space).

3. Unacceptable precision: a peripheral or tangentially transported drill path in relation to the root canal deeming the tooth nonrestorable because of perforation or the inability of the operator to locate and negotiate the root canals

### Statistical Methods

A descriptive analysis regarding treatment duration and quantitative and qualitative volumetric assessment of substance loss after access preparation was performed for each technique. The associations between jaw, technique (freehand or dynamic navigation), and the outcome variables (volume of substance loss and operating time) were determined using analysis of variance models with Tukey-adjusted post hoc pair-wise comparisons. The kappa statistic was used to determine agreement between 2 independent, blinded raters on the qualitative assessment of the drill path. Any disagreements were discussed until a consensus was reached. The association between technique and jaw and qualitative assessment scoring was compared using the Fisher exact test. The significance level was set at .05, and SAS EG v.6.1 was used for all analyses.

## RESULTS

### Quantitative Substance Loss

Overall, dynamically navigated accesses resulted in significantly less mean tooth substance loss in comparison with the conventional freehand technique (27.2 vs 40.7 mm$^3$, $P$ = .0356). The amount of substance loss in the maxillary teeth averaged 35.5 mm$^3$ using dynamic navigation, which was significantly higher than the amount removed for the mandibular teeth (adjusted $P$ value = .0026). The mean substance loss for the freehand technique in the maxillary teeth was 62.2 mm$^3$, which was significantly higher than any other groups ($P < .0001$). The average amount of tooth structure removed in the maxillary teeth using the freehand technique was on average 26.7 mm$^3$ more for the dynamic navigation group ($P < .0001$; 95% confidence interval [CI], 17.99–35.42). The difference between access techniques for the mandibular teeth was negligible (19.1 mm$^3$ and 19.0 mm$^3$, respectively), with an average difference of 0.14 mm$^3$ (adjusted $P$ value = 1.00). The descriptive summary and statistical analyses are described in Table 1 and Figure 2.

### Qualitative Precision

The initial analysis showed near perfect agreement ($\kappa$ = 0.95; 95% CI, 0.87–1.00) for the qualitative assessment of the drill path. There was only one instance of disagreement, which was resolved and a consensus was reached after discussion. There was a significant association between the qualitative rating, technique, and jaw combination ($P$ = .0299). When analyzing by jaw only, a significant difference was present in ratings ($P$ = .0170) but not when assessing by the technique alone ($P$ = .1769). Although not

**TABLE 1 -** The Total Substance Loss and Treatment Duration: Freehand versus Dynamically Navigated Access Cavity Preparation

| | Total substance loss (95% CI) (mm$^3$), *P* = .0001 | | Treatment duration (95% CI) (s), *P* = .0206 | |
|---|---|---|---|---|
| | **Freehand** | **Dynamic navigation** | **Freehand** | **Dynamic navigation** |
| Maxilla | 62.2 (56.0–38.4) | 35.5 (29.3–41.7)* | 598.8 (370.0–827.6) | 164.8 (101.1–228.4)* |
| Mandible | 19.1 (13.0–25.3) | 19.0 (12.8–25.2) | 250.8 (190.6–311.0) | 107.5 (76.6–138.4)* |
| Mean | 40.7 (29.1–52.2) | 27.2 (22.0–32.5)* | 424.8 (289.4–560.2) | 136.1 (101.4–170.8)* |

The *P* value for overall differences based on the procedure method (freehand vs dynamic navigation) and jaw.
*Significant pair-wise comparison between freehand and dynamic navigation.

significant overall, dynamically navigated accesses were associated with higher optimal precision (drill path centered) to locate calcified canals in comparison with the freehand technique (75% vs 45%, *P* = .1053). The freehand access group was associated with higher instances of suboptimal precision (tangentially transported) to locate calcified canals (40% vs 15%, *P* = .1552), especially in the maxillary teeth. Among the 3 instances of unacceptable precision for the freehand group, 2 were associated with perforations in each jaw. There was 1 instance of unsuccessful canal location and perforation within the dynamic navigation group. The access techniques relating to unacceptable precision (ie, the inability to locate the canal and/or perforation) were not statistically significant (15% vs 10%, *P* = 1.00). A descriptive summary of the results and 3D renderings used for qualitative analysis are represented in Figures 1 and 3, respectively.

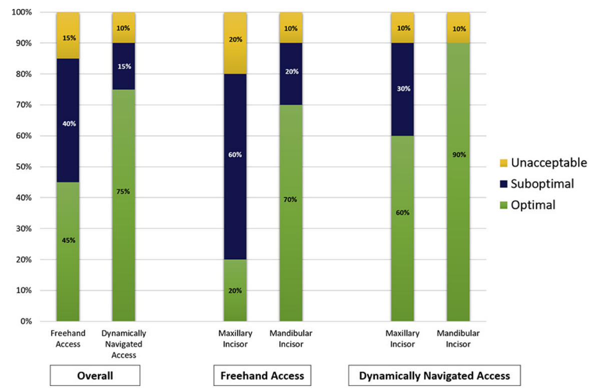


**FIGURE 3 –** Qualitative precision: freehand versus dynamically navigated access cavity preparation.

## Treatment Duration for Locating Calcified Canals

Unequal variance analysis of variance methods had to be used to model the procedure time. Overall, dynamically navigated accesses were prepared significantly faster than freehand preparations ($P < .05$). The procedure time was the longest with the freehand technique in maxillary incisors ($P < .05$). The procedure time had a decreasing trend for freehand procedures on the maxilla, resulting in greater variability in that group than the remaining groups, which did not display an improvement in time across the 10 attempts. Dynamically navigated accesses in mandibular incisors required significantly less time to perform compared with the freehand technique by an average of 2 minutes 23 seconds (adjusted 95% CI, 54.6–232.0 seconds). Maxillary teeth averaged 57.3 seconds slower than the mandibular teeth, but this difference was not statistically significant (adjusted *P* value = .3060). Descriptive summary and statistics analysis are described in Table 1.

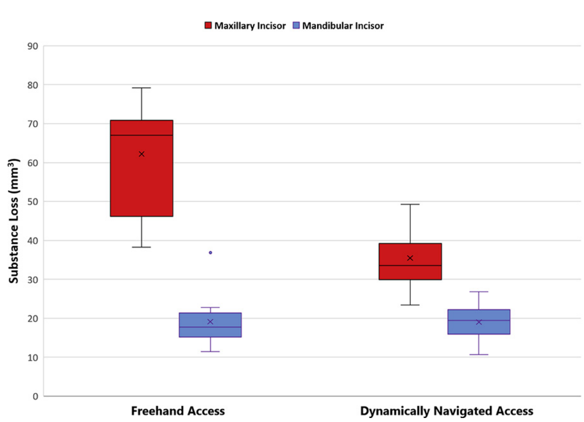


**FIGURE 2 –** Quantitative assessment of substance loss: freehand versus dynamically navigated access cavity preparation. The error bars indicate maximum and minimum observed values, the *circle* indicates outlier, x indicates the mean, the *horizontal line* indicates the median, and the *shaded box* indicates the interquartile range (25th–75th percentile).

## DISCUSSION

This is one of the first studies comparing quantitative assessment of substance loss and qualitative assessment of root canal location between freehand and dynamically navigated access cavity preparations in 3D-printed anterior teeth with simulated calcified root canals. The results show a significant advantage of using dynamic navigation over a freehand approach in order to proficiently and conservatively locate calcified canals.

Sophisticated segmentation software and 3D rendering techniques were used to accurately quantify the difference in substance loss between the two groups. Based on our previous accuracy study, the second-generation Navident system exhibited mean apical deviations ranging from 0.8–1.3 mm and mean angular deviations of 1.7° at the tip of the bur between the planned and prepared access at extreme depths[21]. The high accuracy has been validated through successful location of the canals in this study. However, there was an incident of perforation in the dynamic navigation group. One explanation for this may be attributed to the mid-treatment loss of stability of the jaw tracker on the mannequin model. Alternatively, an inadequate transfer of the anatomic landmarks during the tracing step, rectification of the orientation midtreatment or inadequacy with recalibration may induce unforced errors, leading to an unsuccessful outcome. These errors may worsen in some situations because of a cumulative effect of hand tremors during high-speed drilling, CBCT artifacts, and the learning curve associated with hand-eye coordination of the operator[19,23]. In a clinical situation, a mid-treatment accuracy check through the Navident system or a mid-treatment radiograph short of the target could potentially eliminate any undesirable outcomes.

Although calculation of the total tooth substance loss is clinically important, results can be misinterpreted because of higher substance removal in the coronal third. This is a common modification with access designs for extreme depths to minimize friction with the tooth and shank of the bur to allow for uninterrupted cutting at the tip of burs. Hence, combining quantitative assessment with the quality and the location of substance loss may aid in complete interpretation of precision of the access preparation and restorability of the tooth. Our results indicated statistically comparable volumetric loss of substance for mandibular teeth with both techniques. A contemporary incisal access approach as used in our study instead of traditional cingulum access may be beneficial to maintain a centralized trajectory and preserve pericervical dentin in mandibular incisors[24]. Qualitatively, this approach was still prone to a 30% higher chance of suboptimal precision at extreme depths in locating calcified canals. The results were more significant in maxillary teeth prepared with the freehand technique where twice the amount of substance was lost with twice the tendency to follow a suboptimal trajectory in comparison with accesses leveraged with dynamic navigation. Static-guided access using slow-speed drills followed an optimal trajectory in only 40% of cases in comparison with 75% with dynamically navigated access in our study[16]. These findings corroborate with previous studies that elucidate the disadvantages of freehand techniques when compared with guided techniques in locating calcified canals[25,26].

Customized 3D-printed teeth ensure a high level of standardization and comparability, but one must consider the lack of variation in color or consistency of dentin in these models that may guide the clinician during canal location in natural teeth. Thus, the use of 3D-printed teeth can place the freehand technique at a slight inherent disadvantage in all volumetric and time parameters. In order to mimic a clinically relevant scenario for highly difficult calcified canals and minimize the impact of the learning curve due to standardized teeth and a single operator, the treatment sessions were randomized and spaced out at weekly intervals. Dynamically navigated access preparation was significantly faster than the freehand technique in both arches. However, we did observe a decreasing trend in volumes of substance loss and time required to reach the target for teeth treated in the freehand groups. These findings are consistent with a previous comparative implant placement study in which novice operators gradually required a shorter time to place implants as a result of improved skills using computer-assisted dynamic navigation[27]. Based on our anecdotal evidence, dynamic navigation technology may have a potential educational application to enhance freehand clinical skills and experience for achieving greater predictably in tooth structure preservation.

Slow-speed burs and static-guided approaches offer a more predictable alternative versus freehand drilling in challenging surgical cases[28]. However, the application for endodontic access may be burdened with multiple sources of errors during the workflow because of an inadequate intraoral scan or impression, CBCT artifacts, human error during the design leading to poor alignment during meshing of digital and CBCT renderings and inconsistency in resin thickness during 3D printing causing instability of the guide[29]. In our study, the most updated second-generation navigation system using "trace registration" technology was used to enable efficient transfer of clinical information to the CBCT renderings[20,21]. The ability to optimize all steps and minimize errors of digital workflow related to the static-guided approach have promoted the clinical feasibility of computer-aided dynamic navigation technology for endodontic access to provide the operator with real-time guidance feedback and the ability to adjust the treatment course accordingly.

With advancements of microscopic illumination and magnification along with the information provided by CBCT imaging, a specialist can typically be successful in locating or being in proximity to the orifice of calcified canals as also shown by the operator in this study[30]. However, freehand access techniques may follow a suboptimal trajectory below the level of the cementoenamel junction that may have a detrimental impact on the fracture resistance ability of pericervical and radicular dentin to adapt to catastrophic fractures[8,31]. Additionally, restorative failures caused by crown and root fractures remain one of the leading causes of extraction for endodontically treated teeth[32]. As clinicians committed to saving natural teeth, it is imperative to incorporate predictable dentin-preserving armamentarium and techniques that enhance biomechanical properties and perhaps the long-term prognosis of endodontically treated teeth[33–35].

## CONCLUSION

Within the limitations of this *in vitro* study, overall dynamically navigated access preparations led to significantly less substance loss with optimal and efficient precision in locating simulated anterior calcified root canals in comparison with freehand access preparations.

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

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