Computer-aided dynamic navigation: a novel method for guided endodontics

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Objectives: To investigate the novel use of computer-aided dynamic navigation for guided endodontics. **Method and materials:** Dental casts were fabricated from sets of extracted human teeth. A cone beam computed tomography (CBCT) scan of each cast, with a molded thermoplastic stent and a radiographic marker attached, was obtained and imported into the planning software of a dynamic navigation implant surgery system. Simulating implant surgery but for guided endodontics, the drilling entry point, angle, pathway, and depth of virtual implants were planned for 29 selected teeth. The radiographic marker was replaced with a jaw tag and mounted in a phantom head. A drill tag was attached to the drill handpiece. Following calibration, guided by the stereoscopic motion-tracking camera via the tags and images on a computer monitor providing real-time dynamic plus visual intraoperative feedback, the handpiece was aligned accordingly and endodontic access cavity preparation carried out. Successful root canal location was confirmed using periapical radiographs and CBCT. **Results:** Conservative access cavities were achieved and all the expected canals were successfully located in 26 teeth (n = 29). Due to tracking difficulties, only one canal was located in two maxillary second molars; in a maxillary first molar, only two canals were located and the access preparation for the third canal was misaligned and off-target. **Conclusions:** The results of this study demonstrate the potential of using computer-aided dynamic navigation technology in guided endodontics in clinical practice. *(Quintessence Int 2019;50:196–202; doi: 10.3290/j.qi.a41921)*

Key words: access cavity, cone beam computed tomography, dynamic navigation, endodontics, guided endodontics

In nonsurgical root canal treatment, the access cavity should be prepared according to access requirements whilst avoiding unnecessary and destructive tooth tissue removal.[1] Access cavity preparation that involves both the mesial and distal marginal ridges can reduce cuspal stiffness by up to 63%.[2] Therefore, especially with the advent of "minimally invasive endodontics,"[3,4] access cavities should be kept as conservative as possible. Instead of the traditional endodontic cavity, conservative/contracted endodontic cavity and ultraconservative "ninja" endodontic cavity have been promoted.[5] However, there are a number of clinical scenarios that make the conservative aim challenging. For example, in order to try to locate the root canal system of teeth with calcified coronal pulp space or sclerosed canals, increasing amounts of tooth tissue may need to be removed, compromising structural integrity and risking perforation. In everyday clinical practice, any strategy or guidance that allows the preparation of a minimal access cavity, with decreased risk of iatrogenic damage, and preserves structural integrity while meeting all the access requirements, is to be welcomed.

The concept of utilizing some form of guidance system has been an area of interest for some time in implant surgery. Correct positioning is crucial so that implants are placed at the desired angulation and depth. The introduction of cone beam computed tomography (CBCT) has transformed treatment planning so that the ideal implant position can be determined preoperatively, while taking into consideration important surrounding anatomical structures.[6] Consequently, techniques have been developed in an attempt to improve the accuracy of implant surgery by using guidance based on CBCT data.

Essentially, there are two types of guidance: static and dynamic.[6] Static guidance refers to utilization of a fixed surgical stent, which is made using computer-aided design/computer-assisted manufacture (CAD/CAM), based on the preoperative CBCT scan.[7] Static surgical guides can be tooth-, mucosa-, or bone-supported.[8] A drawback of static surgical guides is that once it is manufactured, the planned angulation, size, depth, or type of implant cannot be easily changed.[9] Other problems include production cost, and time required to plan and to manufacture static guides. In addition, it may not be possible to use static guides in patients with limited mouth opening, or in the second molar regions where access is poorer.[7]

Dynamic guidance is based on computer-aided surgical navigation technology and analogous to global positioning systems or satellite navigation. It has been used in a number of areas in medicine, such as craniomaxillofacial surgery.[10] In dynamically guided implant surgery, the position of the virtual implant, correlated to reference points, is planned using computer software and the imported preoperative CBCT data. A system of motion-tracking optical cameras and images of the position of the virtually planned implant then provides real-time dynamic plus visual feedback to intraoperatively guide surgical implant instruments. Therefore, information that has been planned on the scan is transferred to the real life clinical situation and the exact position of the handpiece can be tracked.[7] Dynamic guidance systems for implant placement that have been developed include RoboDent (RoboDent), X-Guide (X-Nav Technologies), Image Guided Implantology (Image Navigation), and Navident (ClaroNav).

A number of benefits have been attributed to dynamic navigation systems. They reduce errors and are superior in accuracy to manual (freehand) implant placement.[9,11-13] They are comparable or superior in accuracy to other computer-assisted surgical techniques such as static guides.[13,14] Dynamic navigation implant systems have an entry error of approximately 0.4 mm and an angular deviation error of approximately 4 degrees.[7] It has also been reported that the high accuracy of dynamic navigation minimizes the potential risk of damage to critical anatomical structures,[15] including nerves or neighboring teeth, and increases intraoperative safety, resulting in considerable quality improvement in implant surgery.[16] A major benefit of dynamic navigation technology is the flexibility afforded to the operator. Adjustments, dictated by the clinical situation, can be made to the surgical plan at any time.[7] In contrast to static guides, it is claimed that the seamless digital workflow for dynamic navigation allows it to be used for every implant patient.[9]

Fig 1 The Navident (ClaroNav) mobile unit with an overhead light, stereoscopic motion-tracking cameras and a mounted laptop computer with uploaded implant planning software.

To date, guided endodontics for access cavity preparation and canal location in endodontics has focused on the use of static guides.[17-22] The utilization of dynamic navigation for guided endodontic access cavity preparation and root canal

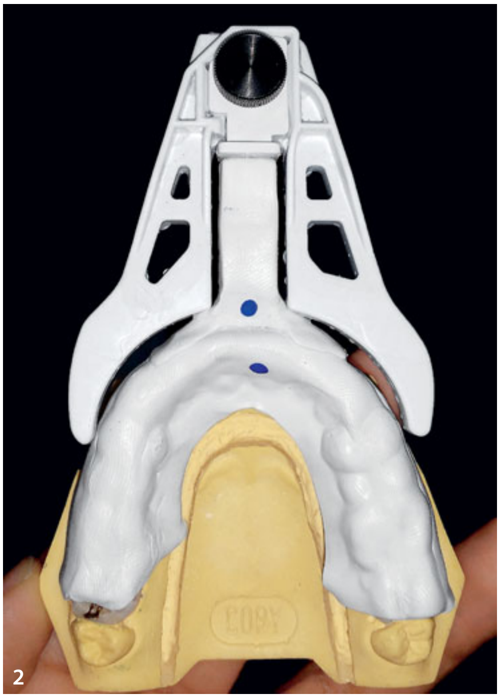


Fig 2 The thermoplastic stent (NaviStent) with attached handle and radiographic (fiducial) marker on the dental cast.

location has yet to be investigated. Therefore, the aim of this study was to investigate the use of computer-aided dynamic navigation for guided endodontics.

Method and materials

Sets of extracted human teeth with fully intact crowns and roots were selected. Periapical radiographs were taken to check that the teeth had not been previously root treated or the pulp space accessed. To prevent radiologic scatter and artifacts, any metallic restorations in the teeth were removed and replaced with glass-ionomer cement (Fuji IX, GC). The apical third of each root was sectioned horizontally with a diamond bur and the canal openings were widened with K-files to size 80. Light-bodied silicone impression material (R&S Turboflex, GCAD) was injected through the apical opening to fill and block the root canal space, simulating canal calcification. The teeth were set-up in individual molds and plaster was poured into it to create three dental casts. A CBCT scan and periapical radiographs were taken of each cast.

The computer-aided dynamic navigation dental implant placement system (Navident, ClaroNav) chosen comprises a mobile unit with an overhead light, incorporating stereoscopic motion-tracking cameras, and a mounted laptop computer with uploaded implant planning software (Fig 1). To utilize the system, for each cast a thermoplastic stent (NaviStent, ClaraNov) was softened in boiling water and molded around the teeth. A handle was attached to the stent using medical-grade cyanoacrylate adhesive (Loctite, Henkel). A radiographic (fiducial) marker, to provide a reference point, was attached to the stent (Fig 2) and a second CBCT scan of each cast was performed. The CBCT scan was imported into the implant planning software to map the dentition and simulate the placement of virtual implants corresponding to the root canal system of 29 selected teeth (six central incisors, two lateral incisors, three canines, three first premolars, eight second premolars, five first

Table 1 The number and type of teeth used in the study and the corresponding results

Tooth type (FDI)	No. of teeth	Expected no. of canal/s	No. of canal/s located	No. of canal/s not located
11	3	3	3	0
12	1	1	1	0
13	1	1	1	0
14	1	2	2	0
15	3	3	3	0
16	1	3	3	0
17	1	3	1	2
21	3	3	3	0
23	1	1	1	0
24	1	2	2	0
25	2	2	2	0
26	1	3	2	1
27	1	3	1	2
33	1	1	1	0
35	1	1	1	0
36	2	6	6	0
41	1	1	1	0
42	1	1	1	0
44	1	2	2	0
45	1	1	1	0
46	1	3	3	0
Total	29	46	41	5

Fig 3 The black-and-white jaw tag attached to the dental cast and mounted in a phantom head, and the black-and-white drill tag attached to the handpiece.

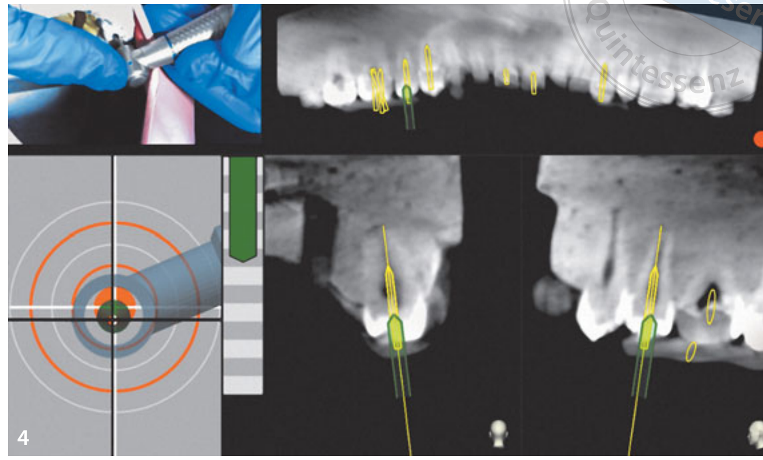


Fig 4 A virtual image, target with crosshair reticule, and drilling depth gauge displayed on the laptop monitor.

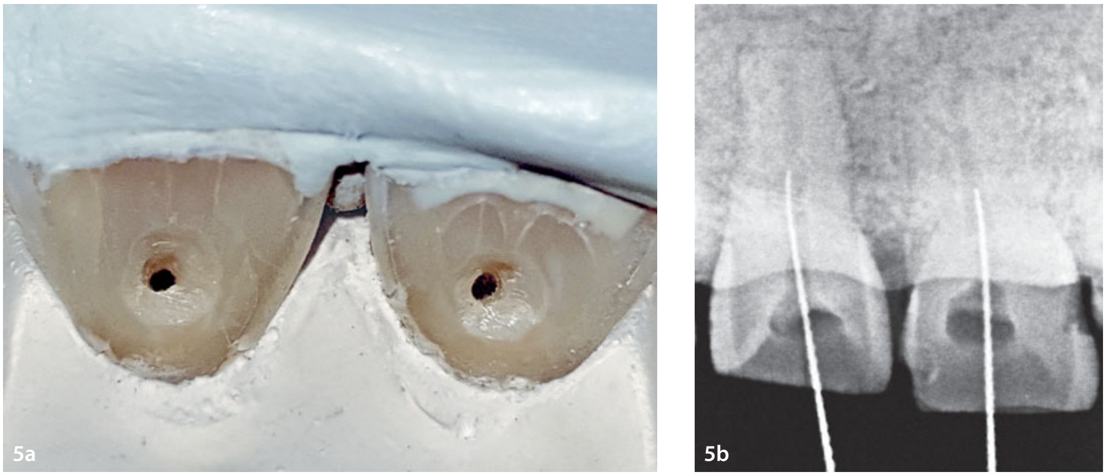
molars, and two second molars) (Table 1). The drilling entry point, angle, pathway, and depth were displayed on the laptop monitor. The stent was cut away to uncover the occlusal and the palatal/lingual surfaces of the selected teeth. The radiographic marker was replaced with a black-and-white jaw tag (tracking array) and the cast was mounted in a phantom head (Fig 3). Another black-and-white drill tag (tracking array) was attached to the handpiece (Fig 3) and the axis calibrated by touching the handpiece tip on a reference point on the jaw tag. An accuracy check, which involved using the handpiece tip to touch a chosen intraoral structure, such as a tooth, was carried out. Accuracy was confirmed when this was correctly represented, matching the images displayed on the laptop monitor.

The handpiece and the jaw were tracked via the attached tags; light from the overhead source reflected back to the built-in high-precision stereoscopic motion-tracking optical cameras. The jaw and drill tags allow for optical triangulation tracking as the data from the CBCT is correlated to the real-time image. Operative information that was planned on the scan was, therefore, transferred to real time and the exact position of the handpiece can be tracked. When the handpiece approached the selected tooth, a virtual image appeared on the laptop monitor; a target with crosshair reticule and depth gauge was displayed (Fig 4). The high-precision stereoscopic motion-tracking camera guides the handpiece to prepare the access cavity; initially, using diamond burs to breach the enamel, followed by round stainless steel burs (ISO 330 206 698 001 160, Hager & Meisinger) for the dentin, at the desired entry point. Recalibration of the handpiece axis was carried out after each bur change.

Intraoperative real-time dynamic and visual feedbacks were provided by the crosshair reticule and depth gauge. Handpiece depth was monitored and indicated by the green bar of the depth gauge; when within 1 mm of the desired depth, the bar's color changed from green to yellow (Fig 4) and then, finally, red when the correct depth was reached. Once this was achieved, stainless-steel K-files (Dentsply Maillefer) were used for canal exploration. Successful canal location and negotiation were confirmed using periapical radiographs and CBCT.

Results

Conservative access cavities (Fig 5) were achieved and all the canals of 26 teeth (n = 29) were successfully located (Table 1). Tracking difficulties were encountered with three molar teeth; only one (palatal) canal each was successfully located in two maxillary (right and left) second molars; in a maxillary left first molar, only two canals (mesiobuccal and palatal) were successfully located and the access preparation for the third canal (distobuccal) was misaligned and off-target (Fig 6).



Figs 5a and 5b Maxillary central incisors: example of *(a)* conservative access cavities and *(b)* periapical radiograph confirming successful canal location.

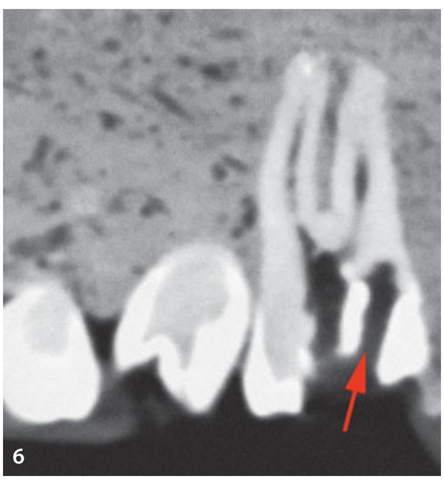


Fig 6 CBCT section of maxillary left first molar in which the two canals (mesiobuccal and palatal) were successfully located and the access preparation for the third canal (distobuccal) was misaligned and off-target (red arrow).

Discussion

The guided endodontics concept has been utilized in both nonsurgical[17-19,22] and surgical[23-26] endodontics; however, they have all relied on some form of static guide. Although developed for implant dentistry, this study successfully demonstrated the potential application of computer-aided dynamic navigation in guided endodontics. For the technology to be fully transferred to everyday clinical endodontic practice, there are a number of considerations.

In order to use such a computer-aided dynamic navigation system, a CBCT scan is always required, whether it is strictly necessary or fully justifiable.[27-29] Even in cases where the patient has already had a previous CBCT scan, another will still be necessary. Otherwise, without a radiographic (fiducial) marker in situ, there is no jaw reference point.

There are cost and time considerations associated with the use of the computer-aided dynamic navigation system. The financial outlay to purchase the system, the cost of a second CBCT scan, and, unless a CBCT scanner is easily accessible or already on site, the need to invest in a scanner. There are running costs; for example, the thermoplastic stent, handle, radiographic marker, and jaw and drill tags are all disposable, single-use items. Although all the prior preparation, such as fabricating the stent, CBCT scanning, and planning the operative procedure can be carried out on the same day, it will still take time; this may translate as extra cost to the patient. However, it could be argued that if its use leads to successful access cavity preparation and canal location, allowing the tooth to be root treated and retained, there are actually cost savings for both the clinician and the patient. Additional advantages include tooth tissue preservation and reduction of the risk of iatrogenic damage, such as root perforation.

There are developments to address the need for a repeat CBCT scan if a previous scan is already available; this involves using 3D surface imaging, equivalent to a "digital impression," to map the dentition to provide the necessary reference point/s (Track and Place, Navident, ClaroNav). This would lead to reduction in radiation exposure, time expenditure, and overall cost.

Part of the thermoplastic stent had to be cut away to expose the area in which drilling will take place. This may potentially weaken or reduce the rigidity of the stent and lead to alignment error. For endodontic application, a more appropriate solution may be to punch a suitable sized hole where the access cavity will be sited, eg the palatal/lingual surface of incisors/canines and the occlusal surface of premolars/molars. A suitable punch would need to be designed for this purpose.

Since the computer-aided dynamic navigation system is meant for implant surgery, the drill tag is designed to fit a slow-speed contra-angle handpiece. However, for access cavity preparation, to penetrate enamel, high-speed handpieces are more efficient and effective. In this study, an initial indentation of the tooth surface was made using the dynamically guided slow-speed handpiece to mark the entry point. This was followed by a free-hand high-speed handpiece to penetrate the enamel before returning to the dynamically guided slow-speed handpiece for the underlying dentin; unfortunately, this creates a stepped access cavity (Fig 5). If drill tags for high-speed handpieces are available, access cavity preparation can all be carried out at high-speed, or slow- and high-speed.

In multi-rooted teeth, static guidance necessitates a number of different stents to permit access to individual canals;[30,31] this is not the case with dynamic guidance. However, with three molar teeth, given their position and the need to angle the handpiece, the guidance system struggled to recognize the attached drill tag when it was out of the optical tracking field. This problem can easily be resolved by redesigning the black-and-white drill tag. Instead of one that is universal, dedicated and individual drill tags should be available for each tooth type and position.

Keeping to "target," maintaining the drilling entry point, angle, pathway, and depth, and controlling the handpiece requires a certain level of technical skill, hand-eye coordination, and manual dexterity. As the "target" was displayed on the laptop monitor, the operator is looking away from the patient instead of at the tooth or their hands. This working position is contrary to the normal experience of facing the patient directly, so there is a learning curve.

Access cavity preparation was planned using the software so that the apical end of the virtual implant was aligned, in a straight line, to the canal entrance. However, in teeth with severely calcified or obliterated root canal space, there may be no patent canal until the middle, or even apical, third of the root. To achieve straight line access to the middle or apical third may require a buccal (facial) access cavity. For esthetic reasons, this may not be acceptable or desired. A possible solution may be to plan and carry out the drilling in two stages: initial drilling aimed at accessing the coronal third then changing direction to access the middle or apical third.

The access cavities prepared using the computer-aided dynamic navigation system had very narrow and parallel walls. While this may be in keeping with the concept of minimally invasive endodontics[4] it may hamper treatment procedures, including the efficacy of root canal instrumentation.[32,33] Nevertheless, any form of guided endodontics, whether static or dynamic, merits further investigation to help overcome the challenges of canal location and negotiation in everyday clinical practice.

Conclusion

The results of this study demonstrate the potential use and feasibility of transferring computer-aided dynamic navigation technology to endodontics, to guide and facilitate access cavity preparation and root canal location.

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References

1. Schäfer E. Preparation of the root canal system. In: Chong BS (ed). Harty's Endodontics in Clinical Practice. 7th edn. Edinburgh: Churchill Livingstone, Elsevier, 2017:113–128.
2. Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. J Endod 1989;15:512–516.
3. Clark D, Khademi J. Modern molar endodontic access and directed dentin conservation. Dent Clin North Am 2010;54:249–273.
4. Gluskin AH, Peters CI, Peters OA. Minimally invasive endodontics: challenging prevailing paradigms. Br Dent J 2014;216:347–353.
5. Plotino G, Grande NM, Isufi A, et al. Fracture strength of endodontically treated teeth with different access cavity designs. J Endod 2017;43:995–1000.
6. D'Haese J, Ackhurst J, Wismeijer D, De Bruyn H, Tahmaseb A. Current state of the art of computer-guided implant surgery. Periodontol 2000 2017;73:121–133.
7. Block MS, Emery RW. Static or dynamic navigation for implant placement-choosing the method of guidance. J Oral Maxillofac Surg 2016;74:269–277.
8. Jung RE, Schneider D, Ganeles J, et al. Computer technology applications in surgical implant dentistry: a systematic review. Int J Oral Maxillofac Implants 2009;24(Suppl):92–109.

9. Block MS, Emery RW, Cullum DR, Sheikh A. Implant placement is more accurate using dynamic navigation. J Oral Maxillofac Surg 2017;75:1377–1386.

10. Ewers R, Schicho K, Undt G, et al. Basic research and 12 years of clinical experience in computer-assisted navigation technology: a review. Int J Oral Maxillofac Surg 2005; 34:1–8.

11. Brief J, Edinger D, Hassfeld S, Eggers G. Accuracy of image-guided implantology. Clin Oral Implants Res 2005;16:495–501.

12. Hoffmann J, Westendorff C, Gomez-Roman G, Reinert S. Accuracy of navigation-guided socket drilling before implant installation compared to the conventional free-hand method in a synthetic edentulous lower jaw model. Clin Oral Implants Res 2005;16:609–614.

13. Block MS, Emery RW, Lank K, Ryan J. Implant placement accuracy using dynamic navigation. Int J Oral Maxillofac Implants 2017;32:92–99.

14. Somogyi-Ganss E, Holmes HI, Jokstad A. Accuracy of a novel prototype dynamic computer-assisted surgery system. Clin Oral Implants Res 2015;26:882–890.

15. Casap N, Wexler A, Persky N, Schneider A, Lustmann J. Navigation surgery for dental implants: assessment of accuracy of the image guided implantology system. J Oral Maxillofac Surg 2004;62(Suppl 2):116–119.

16. Ewers R, Schicho K, Truppe M, et al. Computer-aided navigation in dental implantology: 7 years of clinical experience. J Oral Maxillofac Surg 2004;62:329–334.

17. Connert T, Zehnder MS, Weiger R, Kuhl S, Krastl G. Microguided endodontics: accuracy of a miniaturized technique for apically extended access cavity preparation in anterior teeth. J Endod 2017;43:787–790.

18. Connert T, Zehnder MS, Amato M, Weiger R, Kuhl S, Krastl G. Microguided endodontics: a method to achieve minimally invasive access cavity preparation and root canal location in mandibular incisors using a novel computer-guided technique. Int Endod J 2018;51:247–255.

19. Krastl G, Zehnder MS, Connert T, Weiger R, Kuhl S. Guided endodontics: a novel treatment approach for teeth with pulp canal calcification and apical pathology. Dent Traumatol 2016;32:240–246.

20. Shah P, Chong BS. 3D imaging, 3D printing and 3D virtual planning in endodontics. Clin Oral Investig 2018;22:641–654.

21. van der Meer WJ, Vissink A, Ng YL, Gulabivala K. 3D computer aided treatment planning in endodontics. J Dent 2016;45: 67–72.

22. Zehnder MS, Connert T, Weiger R, Krastl G, Kuhl S. Guided endodontics: accuracy of a novel method for guided access cavity preparation and root canal location. Int Endod J 2016;49:966–972.

23. Ahn SY, Kim NH, Kim S, Karabucak B, Kim E. Computer-aided design/computer-aided manufacturing-guided endodontic surgery: guided osteotomy and apex localization in a mandibular molar with a thick buccal bone plate. J Endod 2018;44:665–670.

24. Giacomino CM, Ray JJ, Wealleans JA. Targeted endodontic microsurgery: a novel approach to anatomically challenging scenarios using 3-dimensional-printed guides and trephine burs. A report of 3 cases. J Endod 2018;44:671–677.

25. Strbac GD, Schnappauf A, Giannis K, Moritz A, Ulm C. Guided modern endodontic surgery: a novel approach for guided osteotomy and root resection. J Endod 2017;43:496–501.

26. Ye S, Zhao S, Wang W, Jiang Q, Yang X. A novel method for periapical microsurgery with the aid of 3D technology: a case report. BMC Oral Health 2018;18:85.

27. AAE and AAOMR. Joint Position Statement: Use of Cone Beam Computed Tomography in Endodontics 2015 Update. Special Committee to Revise the Joint AAE/AAOMR Position Statement on use of CBCT in Endodontics. Oral Surg Oral Med Oral Pathol Oral Radiol 2015:120:508–512.

28. SEDENTEXCT. European Commission. Radiation Protection
No 172 Cone Beam CT for Dental and Maxillofacial Radiology (Evidence-Based Guidelines). Available at: http://www.sedentexct.eu/files/radiation_protection_172.pdf. Accessed 16 January 2019.

29. Patel S, Durack C, Abella F, et al. European Society of Endodontology position statement: the use of CBCT in endodontics. Int Endod J 2014;47:502–504.

30. Dhesi M. The use of navigation aids to facilitate canal location in endodontics. London: MSc Dissertation, 2017.

31. Lara-Mendes STO, Barbosa CFM, Santa-Rosa CC, Machado VC. Guided endodontic access in maxillary molars using cone-beam computed tomography and computer-aided design/computer-aided manufacturing system: a case report. J Endod 2018;44:875–879.

32. Krishan R, Paqué F, Ossareh A, Kishen A, Dao T, Friedman S. Impacts of conservative endodontic cavity on root canal instrumentation efficacy and resistance to fracture assessed in incisors, premolars, and molars. J Endod 2014;40:1160–1166.

33. Moore B, Verdelis K, Kishen A, Dao T, Friedman S. Impacts of contracted endodontic cavities on instrumentation efficacy and biomechanical responses in maxillary molars. J Endod 2016;42:1779–1783.

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