Journal of Dental Sciences (2021) 16, 45—50

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Journal of Dental Sciences

Original Article

Accuracy of root-end resection using a digital guide in endodontic surgery: An *in vitro* study

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Received 6 March 2020; Final revision received 27 June 2020
Available online 16 August 2020

KEYWORDS
Accuracy;
Root-end resection;
3D printing;
Digital guide;
Endodontic surgery

Abstract *Background/Purpose:* It is difficult to achieve accurate root-end resection clinically. This *in vitro* study was conducted to evaluate the operation accuracy of a digital endodontic surgical guide.
Materials and methods: 56 extracted maxillary anterior teeth were prepared for endodontic surgical models. The models were randomly divided into 4 groups equally according to the guide (with guide/no guide) and the operator (experienced/inexperienced). Endodontic microsurgeries were performed on models in each group. The deviations in length and angle of the root-end resection were measured based on the optical scanning data of the pre- and postoperative teeth. The general linear model was performed to analyze the effect of a guide on root-end resection deviation.

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https://doi.org/10.1016/j.jds.2020.06.024

Results: Using a guide, the mean length deviation for experienced/inexperienced operators reduced from 0.99 mm (95% CI [confidence interval, CI], 0.66–1.33 mm)/1.18 mm (95% CI, 0.50–1.86 mm) to 0.31 mm (95% CI, 0.20–0.42 mm)/0.31 mm (95% CI, 0.24–0.37 mm). The mean angle deviation for experienced/inexperienced operators reduced from 16.74° (95% CI, 10.61–22.86°)/15.06° (95% CI, 9.19–20.94°) to 5.04° (95% CI, 3.31–6.77°)/6.79° (95% CI, 4.91–8.67°). The difference was significant between procedures performed with and without a guide ($P < 0.01$).

Conclusion: Application of the digital guide in *vitro* endodontic surgery could improve the accuracy of root-end resection.

Introduction

In recent years, success rate of endodontic surgery has increased from 44.2-53.5% to 90.5–91.1%, with the advance of cone beam computed tomography (CBCT) and surgical instruments and materials.[1–3]

One of challenges for practitioners in endodontic surgery is accurate location and resection of root-end. To control infection better, reduce dentinal tubule exposure, minimize the possibility of microleakage and maximize the remaining tooth tissue, in modern endodontic surgery, 3 mm of the root end is generally removed, and the resection plane is made perpendicular to the long axis of the tooth.[4–8] However, it is clinically difficult to achieve accurate root-end resection due to the limited field of view, the inconvenient perspective, and interferential bleeding, among other factors.

Previous studies have showed that digital guide is a useful tool in oral implants and can improve the accuracy of the operations.[9,10] But in endodontics, the use of digital guide is few, as the endodontic guides require higher accuracy.

The application of digital guides in endodontics were mainly in root canal localization and endodontic surgery.[11–22] Digital guides were first used in endodontic surgery in 2007.[17] The indicators used to evaluate results in previous studies mainly consisted of qualitative clinical indicators, e.g., whether the lesion healed.[18,23] There are few quantitative studies of digital endodontic surgical guides. In these studies, length deviation was used as an indicator, but angle deviation was not evaluated.[17,22,24]

In a previous study, the independently designed digital guide with grooved guide track for endodontic surgery was established.[25] Therefore, the main purpose of this study was to evaluate the accuracy of the endodontic surgical guide *in vitro* by evaluating both root-end resectional length deviation and angle deviation.

Materials and methods

Model preparation and 3D data acquisition

Ethical approval was obtained from the Ethics Committee of Peking University School and Hospital of Stomatology, P. R. China (No. PKUSSNCT-15A07).

The detailed experimental procedures are described as follows.

Fifty-six extracted maxillary anterior teeth with complete roots and apexes were selected. Root canal therapy was conducted on the teeth. The curvatures of the roots were less than 10° according to the method of Schneider.[26] Preoperative optical scans of the teeth were obtained using a 3D scanner with an accuracy of 0.02 mm (Activity 880, Smart Optics Corporation, Bochum, Germany).

Models were prepared for endodontic surgery. A mixture of sawdust and gypsum was used to simulate alveolar bone and inlay wax was used to simulate gingiva.[27] CBCT (NewTom VGi, QR Corporation, Verona, Italy; voxel size: 0.076 mm) and optical scans of the models were taken. 3D CBCT reconstructions were produced to yield virtual models of the extracted maxillary anterior teeth and hard tissue contours for the models.

The models were randomly divided into 4 groups according to the guide (with guide/no guide) and the operator (experienced/inexperienced), 14 in each group. The experienced operator was an endodontic specialist who had performed more than 100 cases of endodontic microsurgery. The inexperienced operator was a resident who had only training on endodontic microsurgery but had not done a clinical case.

Computer-aided design and 3D printing of endodontic surgical guides

The guide designed by Peng et al. with a grooved guide track was used in this study.[25] The bottom edge of the guide track was one of the root's axial planes, which was 3 mm from the apex. The brief design process is described as follows.

First, the optical scans of the models, the virtual models of the teeth, and the hard tissue contours of the models were introduced into Geomagic Studio 2012 (Raindrop Corporation, Morrisville, NC, USA). The 3D positional relationship of the teeth, dentition, alveolar bone, and gingivae were simulated in the software. It was taken as the root-end resection standard to remove the apical 3 mm, perpendicularly to the long axis of the tooth. A virtual model of the guide was then established based on the spatial geometric relationship (Fig. 1). Finally, polylactic acid was selected as the printing material, and a fused

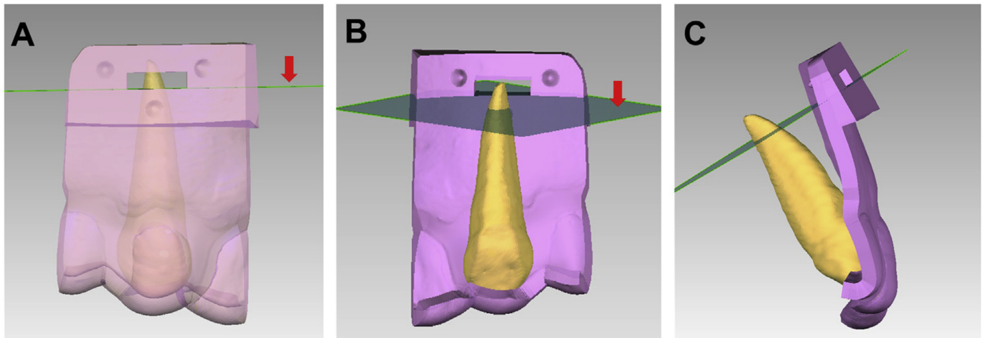

Figure. 1 Virtual model of the digital guide for endodontic surgery. The red arrow indicates the location of the axial plane 3 mm from the apex.

deposition modeling (FDM) 3D printer (Lingtong III, Beijing SHINOTECH Co., Ltd., Beijing, China) was used to print the guide.

Endodontic microsurgeries performed on models

The models were fixed on the head-simulator (Nissin Dental Products INC, Kyoto, Japan) to mimic the clinical environment. Endodontic surgeries were performed under surgical microscope (OPMI Pico, Carl Zeiss, Oberkochen, Germany) with the guide by experienced/inexperienced operators on models (Fig. 2). After the simulated gingiva was removed, the guide was put in place on the teeth and the simulated alveolar bone. Apicoectomy was performed using a 1.6-mm-diameter fissure bur with a depth stopper.

Without the guide, endodontic microsurgeries were also performed by experienced/inexperienced operators on models according to CBCT images. Uniform size was used for bone fenestration in all groups.

The time required from bone fenestration to root-end resection was recorded in all groups.

Postoperative evaluation of length/angle deviations of root-end resection

After surgeries, the maxillary anterior teeth were removed from the models in all groups. Postoperative optical scans of these teeth were obtained. The pre- and postoperative 3D optical scans of the teeth were compared blindly by an evaluator (not the designer or the operators) in Geomagic Studio 2012 (Raindrop Corporation). Both the length

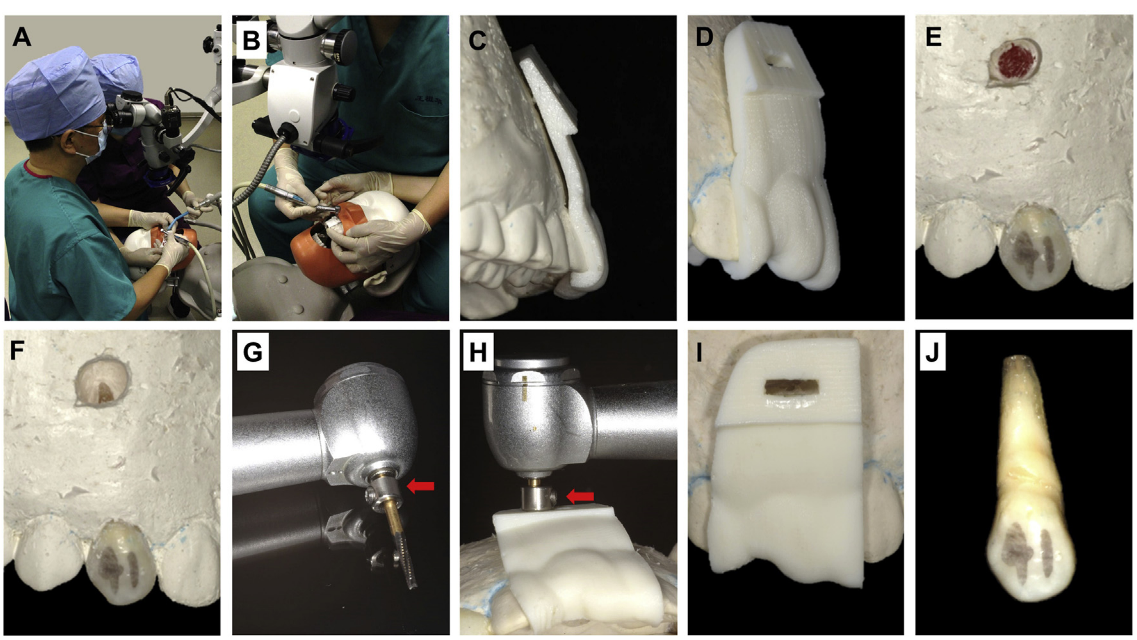

Figure. 2 Guided surgical procedure. (A, B) The experimental scene to mimic the clinical environment. (C, D) Initial guide placement. (E) Exposure of the periapical lesion. (F) Removal of the periapical lesion. (G) The depth stopper (red arrow) on the bur. (H, I) Guided root end removal. (J) The tooth after surgery.

deviation along the direction of the preset long axis of the teeth and the angle deviation were measured.

The guided root-end resectional length deviation was measured again in 2 weeks to test the intra-evaluator consistency. The first measurements were used for final analyses.

Statistical analysis

The intraclass correlation coefficient was used to test the intra-evaluator agreement of the root-end resection deviation measurements.

All data were taken as absolute values. Normality was tested in each group with the Shapiro—Wilk test. The general linear model (GLM) was used to analyze the effects of the guide and operator experience on length/angle deviation of root-end resection and operation time.

The level of significance was set at $\alpha = 0.05$. The statistical analyses were performed using SPSS (version 20.0, IBM, Chicago, IL, USA).

Results

The intraclass correlation coefficient value of root-end resection deviation was 0.977 for 2 measurements. The means and standard deviations for deviations of root-end resection are shown in Table 1. There is no interaction between the guide and operator experience.

Both length and angle deviations of root-end resection were significantly lower when a guide was used than when no guide was used ($P < 0.01$). In general, the length deviation of root-end resection in procedures performed with a guide was 0.78 mm (25.94%) lower than the mean values achieved without a guide. The angle deviations achieved with a guide was 9.99° (11.09%) lower than the mean values achieved without a guide.

When a guide was used, there were no significant differences in the deviations of root-end resection between experienced and inexperienced operators ($P > 0.05$). The length deviation was 0.31 mm (95% CI, 0.20—0.42 mm) for the experienced operator and 0.31 mm (95% CI, 0.24—0.37 mm) for the inexperienced operator, respectively. The angle deviation was 5.04° (95% CI, 3.31—6.77°) for the experienced operator and 6.79° (95% CI, 4.91—8.67°) for inexperienced operators, respectively.

The distribution of length deviation when the deviation direction is taken into account is shown in Fig. 3.

When using a guide, the operation time was 155.71 s for the experienced operator and 189.75 s for the inexperienced operator, respectively. The time was slightly shorter than that spent without a guide (187.67 s and 260.08 s, respectively) (Table 1), but no significant difference was found ($P > 0.05$).

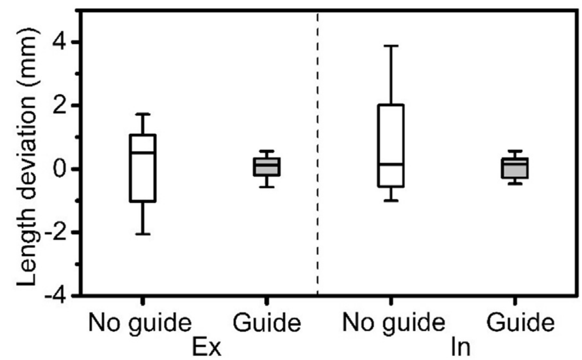

Figure. 3 Differences in length deviation of root-end resection performed with/without guides. The negative value indicates the length of root-end resection is less than 3 mm, otherwise greater than 3 mm. Ex, the experienced; In, the inexperienced. There were no significant differences between the groups ($P > 0.05$).

Discussion

It is critical to resect 3 mm of apex perpendicularly to the long axis of the tooth in the procedure of endodontic surgery. Previous studies showed that length and angle deviation of root-end resection are associated with success for endodontic surgery. When the root-end resection is longer than 3 mm, it may affect the stability of teeth and increase the possibility of communication of the lesion and the periodontal pocket.[28] However, when the root-end resection is shorter than 3 mm, it may result in insufficient infection control and affect the long-term prognosis of teeth.[29] It has been reported that the level of root-end resection and the success rate of the procedure are negatively correlated.[30] Therefore, the preset value was to remove apical 3 mm perpendicularly in this study.

However, it is difficult to perform accurate root-end resection due to the restriction of anatomical structures and interferential factors. Application of the oral implant digital guide has brought us a light on this problem.[9,10] But the accuracy requirement of endodontic surgery is higher than that of oral implant.

Therefore, a series of measures were taken to ensure the operation accuracy of the endodontic surgical guide in this study. High resolution CBCT data and high accuracy

Table 1 Differences in length/angle deviation of root-end resection and operation time between groups. The operation time indicates that consumed in procedures including root-end resection and osteotomy.

	Length deviation (mm)		Angle deviation (°)		Operation time (s)	
	Guide	No guide	Guide	No guide	Guide	No guide
Experienced	0.31 ± 0.19[a]	0.99 ± 0.58[b]	5.04 ± 2.99[a]	16.74 ± 10.61[b]	155.71 ± 75.13	187.67 ± 77.65
Inexperienced	0.31 ± 0.12[a]	1.18 ± 1.18[b]	6.79 ± 3.25[a]	15.06 ± 10.17[b]	189.75 ± 85.08	260.08 ± 153.68

a, b: The difference between the groups was significant ($P < 0.01$).

optical scan data were obtained and fused to reconstruct the models accurately in 3 dimensions. The guide is designed to be supported by hard tissues to ensure the stability between the guide and tissues. The apex can be explored according to its relationship with the grooved guide track. The length and angle of root-end resection are controlled by the grooved guide track, and the depth of operation is controlled by a depth stopper. According to the results, the introduction of the digital guide in this study reduced length deviation ($P < 0.01$), which is similar to other studies.[17,22,24] To our knowledge, this is the first study taking angle deviation as evaluating indicator.

Most guides for endodontic surgery were designed by implant planning software.[17–22] In this study, general software (Geomagic Studio 2012) was applied, thus providing a reference for the development of special software for endodontic surgical guides.

The FDM process has high repeatability and stability. The printing error was only 0.013 mm compared with the CAD data.[31] The printer is characterized by its small size, high efficiency, easy operation, and low cost.[31,32] It is favorable for chairside printing. However, the abrasion resistance of polylactic acid is worse than that of other printing materials (metal or ceramic). In some case reports, a metal sleeve was used in the guide track.[19,23] Metal or ceramic printing can be taken into account in further research.

The preoperative long axis of the teeth was defined by the line between the imaging apex and the central point of the axial plane 3 mm from the apex. The optical scan has a high accuracy of 0.02 mm. The pre- and postoperative optical scanning data were matched and compared to evaluate the deviation of root-end resection. This method can ensure the consistency of the long axis of the postoperative teeth with pre-operative.

In this study, the length and angle deviation of root-end resection were selected as evaluation indicators. When the preset value was to remove the apical 3 mm perpendicularly to the long axis, infection can be controlled better under the premise of guaranteeing the crown-root ratio. However, in clinical practice, the "3 mm principle" is not applicable to all cases. The length of root-end resection is also affected by the locations of the lateral canals and the length of the post, among other factors.[5] In fact, the guide used in this experiment can be designed for different root-end resection lengths and angles according to clinical needs.

This study is an *in vitro* experiment. The selected maxillary anterior teeth were with single and straight root canals. However, many other factors should be considered in clinical situations, such as the interference of prosthetic artifacts on CBCT imaging, the applicability of the guide for curved apex or inclined root, the influence of soft tissues on field of view and drilling approach, the management of the size of bone window, and the requirement for heat dissipation during operation. There are only two operators in this study, which may cause bias on the influence of experience on the accuracy of root-end resection. The effect of experience needs further study.

In conclusion, for two operators with different levels of clinical experience, the application of the digital guide can improve the operation accuracy of endodontic surgery. The feasibility of the guide in complex situations and clinical scenarios needs to be verified in further trials.

Declaration of competing interest

The authors declare no conflicts of interest associated with this manuscript.

Acknowledgments

This study was supported by the New Medical Technology Program of Peking University Hospital of Stomatology (PKUSSNCT-17B02).

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