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# Influence of deviation tolerances on the positioning accuracy using computer aided dynamic navigation in endodontic surgery: a proof-of-concept

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## Abstract

**Background** The operation accuracy of dynamic navigation is affected by deviation tolerance settings. This in vitro study was aimed to assess the influence of distance and angle deviation tolerances (DDT and ADT) on positioning accuracy in endodontic surgery using dynamic navigation.

**Materials and methods** Standardized models were designed and three-dimensional (3D) printed. The drilling depth was 15 mm, where hemispherical cavities were reserved. According to the DDTs and ADTs, they were divided into five groups (n = 10), and the tolerances of distance/angle deviation were set at 0.3 mm/5°, 0.6 mm/3°, 0.6 mm/5°, 0.6 mm/7°, and 0.9 mm/5°. During navigation guidance, the operation was completed from the model surface to the cavity, the trajectory of the approach was fitted and compared with the design path, and the operational accuracy was calculated and analyzed using one-way ANOVA.

**Results** When the ADT was 5°, the positioning two-dimensional (2D) distance deviation of the DDT 0.3 mm group and the 0.6 mm group were 0.52 ± 0.14 mm and 0.50 ± 0.07 mm, respectively, smaller than 0.73 ± 0.17 mm of the 0.9 mm group ($P$ <.01). The positioning 3D distance deviation of the 0.3 mm group and the 0.6 mm group were 0.55 ± 0.15 mm and 0.53 ± 0.07 mm, respectively, smaller than 0.74 ± 0.17 mm of the 0.9 mm group ($P$ <.01). When the DDT was set as 0.6 mm, the positioning angle deviation of the ADT 3° group and the 5° group were 2.21 ± 0.42° and 2.60 ± 0.59°, respectively, smaller than 4.72 ± 0.64° of the 7° group ($P$ <.01).

**Conclusion** A 0.6 mm DDT and 5° ADT can reduce the positioning deviation of dynamic navigation and obtain better operability. The deviation tolerance of 0.6 mm/5° is suggested for application of dynamic navigation in endodontic surgery. It might improve the operation efficiency and ensure positioning accuracy.

**Keywords** Dynamic navigation, Distance deviation tolerance, Angle deviation tolerance, Accuracy, Endodontic surgery

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## Background

Dynamic navigation is a digital technology that can track and guide targets in real time. Its application in clinical oral surgery is considered to improve the operation accuracy, reduce surgical complications and might increase the confidence of the surgeons [1–3]. In endodontic surgery, the accurate and efficient apical localization of the affected teeth is challenging in cases with intact bone cortex and close to crucial structures [4–7]. Although dynamic navigation has been preliminarily applied in endodontic surgery, its use was described in a few case reports and various preliminary studies [8–15]. It has achieved good clinical results and follow-up radiographic assessments revealed periapical bone healing in the majority of affected teeth. Dynamic navigation is believed to be feasible in endodontic surgery and a promising development will occur in dentistry.

Up to date, the main method of dynamic navigation application in endodontology is similar to that in implantology [16–18]. In terms of targeting the calcified root canal and grinding the fiber post, the operative approach is the same as that of implant surgery [19–22]. Deviation tolerance is one of the key parameters during dynamic navigation, which indicates the maximum distance/angle deviation allowed between the actual (real-time) drilling point and the virtually designed one. The deviation tolerance is set artificially. When it is exceeded, the operation must be stopped, and the position and direction of the drill should be corrected.

Since there is no specific mode of dynamic navigation for endodontology, the procedure needs to be completed with implant dynamic navigation software. However, the tolerance of distance/angle deviation in implant dynamic navigation can reach 0.9 ~1 mm/7°. Considering that the goal of root-end resection in endodontic surgery is to remove 3 mm perpendicularly to the long axis of the tooth, the requirement for positioning accuracy is higher than that in implants [23–25]. Direct application of appropriate deviation tolerance for dental implantation during dynamic navigation cannot meet the accuracy requirements of endodontic surgery.

Although a smaller deviation tolerance can theoretically improve the positioning accuracy during dynamic navigation, blindly reducing the deviation tolerance will increase the operation difficulty and reduce the efficiency of the surgical intervention. Thus, it is essential to verify the positioning accuracy during dynamic navigation using different deviation tolerances in endodontic surgery, obtain reference values for DDTs and ADTs that are suitable for guiding clinical operations. Further, it is needed to provide reference levels on the positioning accuracy and operation efficiency during dynamic navigation in endodontic surgery for in vitro or clinical quantitative research.

There is no research on the positioning accuracy during dynamic navigation using different deviation tolerances. In the present proof-of-concept study, a standardized model was used to quantitatively examine the positioning accuracy during dynamic navigation using different DDTs and ADTs at a fixed depth.

## Materials and methods

### Computer-aided design and 3D-printed standardized models

A standardized model was designed using Rhino 7.0 software (McNeel, Seattle, WA, USA) specially for this study (Fig. 1a) [26]. The model featured a 5-mm-diameter hemispherical cavity, 15 mm away from the outer surface. A 5-mm-diameter channel cavity was created at the rear of the hemispherical cavity to allow removal of the 3D-printed supporting material (Fig. 1b). A cantilever was designed on the side of the model to place the fixture (Fig. 1c). A groove measuring 44 mm wide was reserved above the model to allow placement of the registration device required for the dynamic navigation (DCARER, Suzhou, China) (Fig. 1d).

The data of the model were exported in stereolithography (STL) format and uploaded to the Objet30 Prime printer (Stratasys, Eden Prairie, MN, USA). Models with a total of 50 identical hemispherical cavities were printed using VeroClear resin (Stratasys, Eden Prairie, MN, USA).

The sample size was estimated based on a prior study evaluating accuracy of endodontic access cavities using dynamic navigation (n =10) [27]. To evaluate the impact of different ADT/DDT in this study, hemispherical cavities were coded, randomly and equally allocated into 5 groups, namely 0.3 mm/5°, 0.6 mm/3°, 0.6 mm/5°, 0.6 mm/7°, and 0.9 mm/5°. The values for grouping referred to the default ADT/DDT for implant placement in the dynamic navigation system of 0.9 ~ 1 mm/7°.

### Complete approach of trephine in terms of different deviation tolerances

The registration device was securely fixed in the designated groove using silicone rubber impression material (HUGE, Shanghai, China) (Fig. 2a). Following the curing of the silicone rubber, cone beam computed tomography (CBCT, New Tom VGi, QR Corporation, Verona, Italy; layer thickness 125 mm, FOV 8 × 8 cm, 110 kV, 4.00 mA) scans of the model were obtained. The CBCT data were then imported into the dynamic navigation software to establish the guidance plan (Fig. 2b- 2e).

A 4.5-mm-diameter trephine (Changsha Tiantian, Changsha, China) was selected for the access procedure

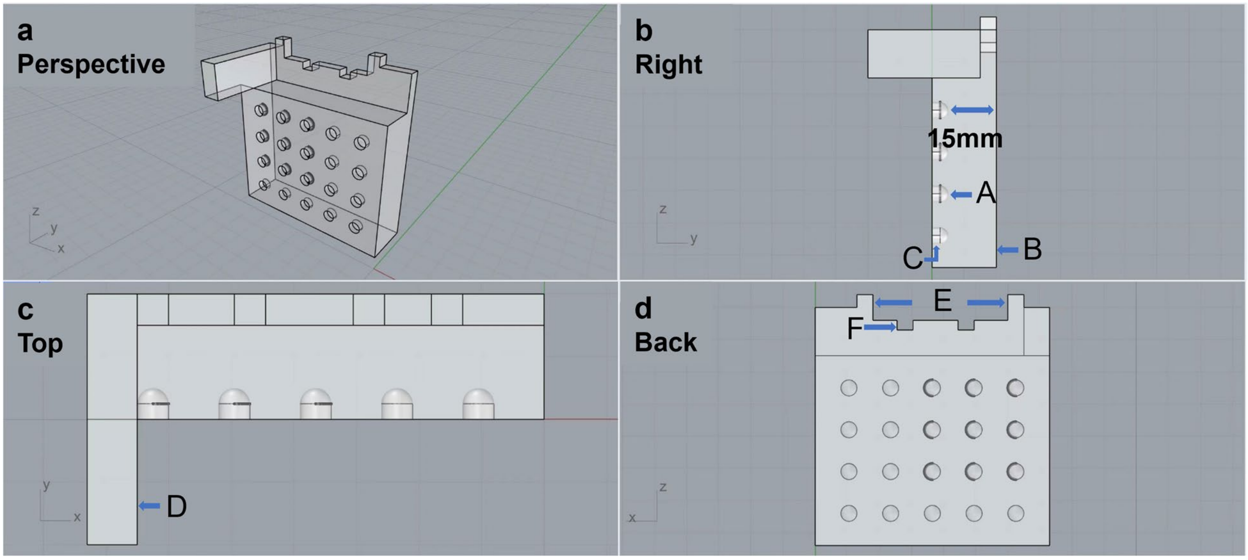


**Fig. 1** Design of the model for evaluating deviation tolerances. (**a**) 3D perspective view of the model; (**b**) Side view of the model. The distance between the hemispherical cavity (**A**) and the outer surface (**B**) is 15 mm. The "C" displays the channel cavity; (**c**) Top view of the model. The "D" exhibits the cantilever for placing the fixture; (d) Back view of the model. The "E" demonstrates the groove reserved for placing the registration device. The "F" indicates the retention slot with the aid of silicone rubber

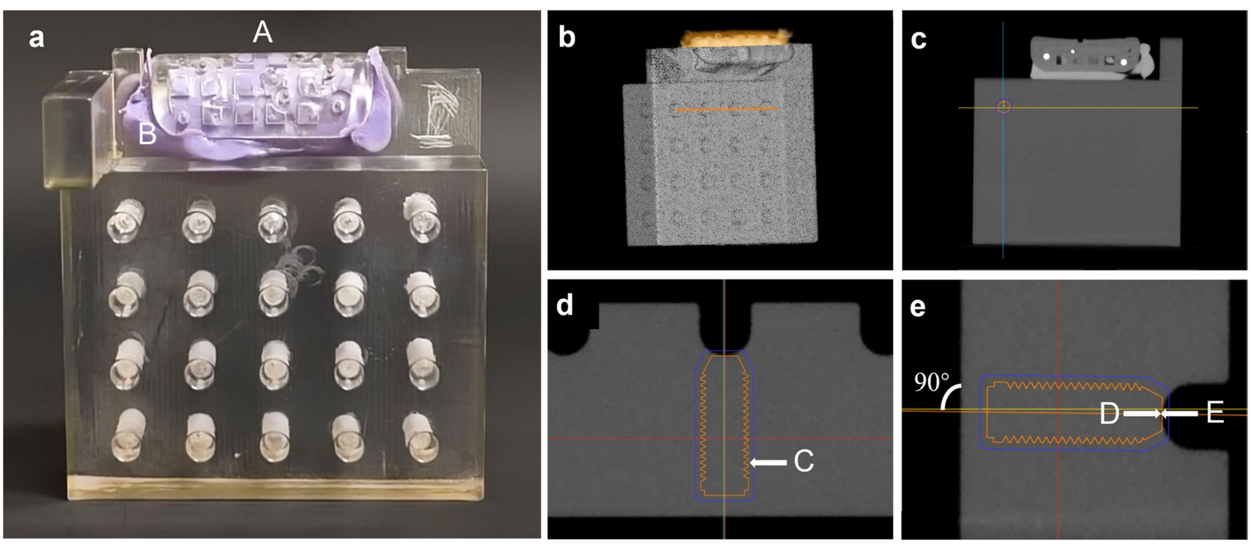


**Fig. 2** Access planning under dynamic navigation. (**a**) The registration device (**A**) was fixed in the groove of the model using silicone rubber (**B**) for CBCT scans; (**b**) 3D images of the approach design in the navigation system; (**c**) Coronal plane view; (**d**) Axial plane view. The "C" displays the implant; (**e**) Sagittal plane view. The "D" exhibits the center of the implant front. The "E" demonstrates the front of the hemispherical cavity

on the model. In the software, an implant was chosen to simulate the access for entry of the trephine, which also had a diameter of 4.5 mm. The implant was adjusted to the target position, where the implant was perpendicular to the outer surface of the model, and the center of the implant front reached and was tangent to the front of the hemispherical cavity (Fig. 2d, 2e).

The handpiece to be used was calibrated into the navigation system (Fig. 3a). Then the model was fixed on the desktop using a clamp, and the reference board was also fixed (Fig. 3b). The calibrated handpiece was utilized to match the physical models with the CBCT data (Fig. 3c).

During the dynamic navigation procedure, the calibrated handpiece and the trephine were employed to

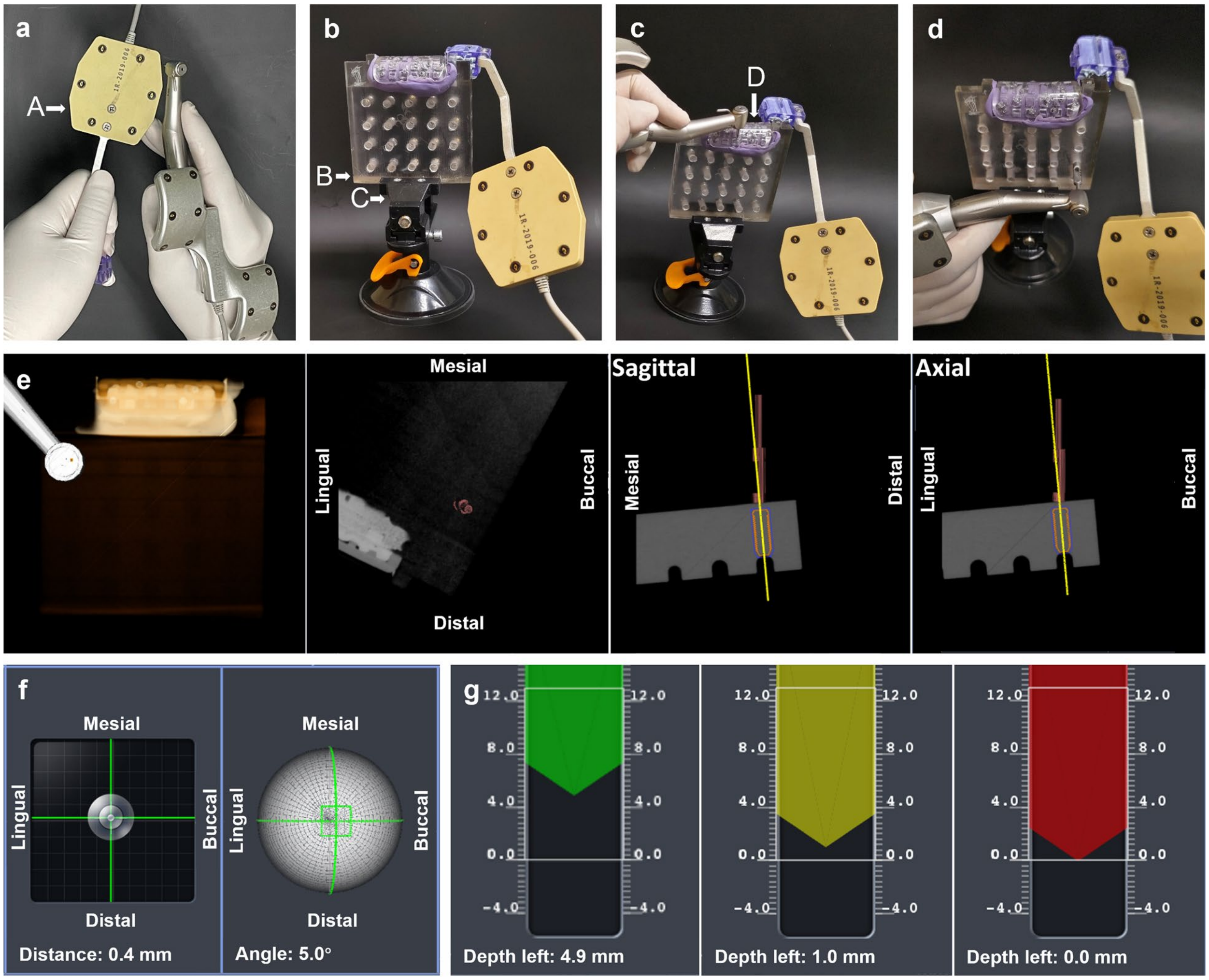


**Fig. 3** Access execution under dynamic navigation. (**a**) Calibrate the handpiece into the dynamic navigation system with the reference board (**A**); (**b**) Fix the model (**B**) and the reference board on the desktop using a clamp (**C**); (**c**) Match the physical models with the CBCT data using the calibrated handpiece and the registration device (**D**); (**d**) The calibrated handpiece with the trephine were used to execute navigated access on the model; (**e**) The model and the trephine exhibited on the dynamic navigation software; (**f**) The distance and angle deviation; (**g**) Depth left was displayed accordingly during the drilling process

establish access (Fig. 3d). If any distance or angle deviation exceeded the specified tolerances, the operation was temporarily halted, and the position or angle of the trephine was adjusted accordingly (Fig. 3e, 3f). As indicated by the navigation system, drilling was stopped once the depth left was 0.0 mm (Fig. 3g).

All the access procedures were carried out by an endodontist with more than 10 years of endodontic microsurgery. In order to master the operation during dynamic navigation, the endodontist had practiced more than 7 times, and the learning curves had reached a stable level. No significant differences were found between the endodontist and other skilled operators in our previous studies ($P > 0.05$) [26, 28].

### Reconstruction and analysis of CBCT data of the models before and after the access operation

The CBCT images of the postoperative models were taken under the same conditions as those before the operation. The CBCT data were imported into MIMICS 21 (Materialise, Glen Burnie, MD, USA) to reconstruct three-dimensional structures of the postoperative model. The reconstructed models in STL format were imported into Geomagic Control software (Geomagic, Morrisville, NC, USA) to automatically fit the channels of the trephine approach. The two-dimensional distance deviation, three-dimensional distance deviation, depth deviation, angle deviation and initial position deviation were calculated between the final position of the trephine and the planned position (Fig. 4) [29, 30]. Reconstruction and calculation were conducted by an examiner different from the operator.

## Statistical analysis

The data were imported into SPSS software (IBM, Chicago, IL, USA) to compare the difference between the final position of the trephine and the planned position for different DDTs (0.3 mm/5°, 0.6 mm/5°, 0.9 mm/5°) when the ADT was fixed. One-way ANOVA was used to determine whether there was a significant difference ($P < 0.01$) in the data between the groups with different DDTs. If there was a difference between groups, the LSD post hoc test was performed to determine whether the difference in data between the two groups was statistically significant ($P < 0.01$).

Similarly, the data were analyzed based on different ADTs (0.6 mm/3°, 0.6 mm/5°, 0.6 mm/7°) when the DDT was fixed. One-way ANOVA was also applied ($P < 0.01$) between the groups with different ADTs. If there was a difference between groups, the LSD post hoc test was conducted as well ($P < 0.01$).

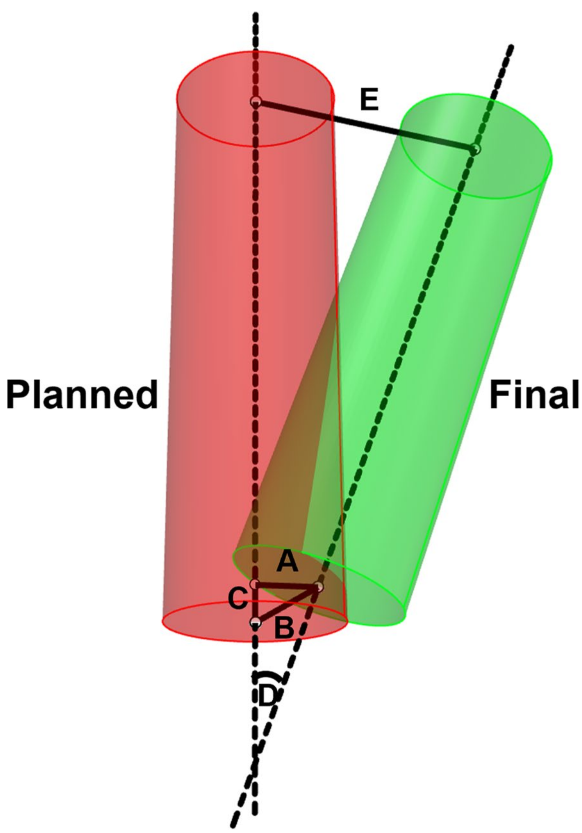


**Fig. 4** Evaluation indicators of the deviation between the final position of the trephine and the planned position. The "A" demonstrates two-dimensional distance deviation. The "B" indicates three-dimensional distance deviation. The "C" exhibits depth deviation. The "D" displays angle deviation. The "E" shows initial position deviation

## Results

When the ADT was 5°, the positioning distance deviation (two-dimensional and three-dimensional) of the DDT for the 0.3 mm group and the 0.6 mm group were smaller than that for the 0.9 mm group ($P < 0.01$). When the DDT was set at 0.6 mm, the positioning angle deviation of the ADT for the 3° group and the 5° group were smaller than that for the 7° group ($P < 0.01$).

## The influence of different DDTs on positioning accuracy during dynamic navigation

Positioning distance deviation and angle deviation regarding to different DDTs is shown in Fig. 5a and Fig. 5b. There were significant differences ($P < 0.01$) between groups using different DDTs in terms of the two-dimensional distance deviation and the three-dimensional distance deviation.

There was no significant difference in the two- and the three-dimensional distance deviations between 0.3 mm and 0.6 mm of DDTs ($P > 0.01$). There was a statistically significant difference in the two- and three-dimensional distance deviations between the groups whose DDT was 0.3 mm and 0.9 mm ($P < 0.01$). There was a statistically significant difference in the two- and the three-dimensional distance deviations between the groups whose DDT was 0.6 mm and 0.9 mm ($P < 0.01$). There was no significant difference in the depth deviation, angle deviation, and initial position deviation regarding to different DDTs of dynamic navigation positioning accuracy ($P > 0.01$).

As the DDT increased, the positioning accuracy during dynamic navigation decreased. For the DDTs of 0.3 mm and 0.6 mm, positioning during dynamic navigation was highly accurate, with an average three-dimensional distance deviation of only $0.54 \pm 0.12$ mm and an average positioning angle deviation of only $2.93 \pm 1.02°$.

## The influence of different ADTs on the positioning accuracy during dynamic navigation

Positioning distance deviation and angle deviation regarding to different ADTs is shown in Fig. 5c and Fig. 5d. There were intergroup differences ($P < 0.01$) in the angle deviations of positioning during dynamic navigation among different ADTs.

There was no significant difference ($P > 0.01$) in the angle deviation between 3° and 5° of ADTs. There was a statistically significant difference in the angle deviations between the groups whose ADT was 3° and 7° ($P < 0.01$). There was a statistically significant difference in

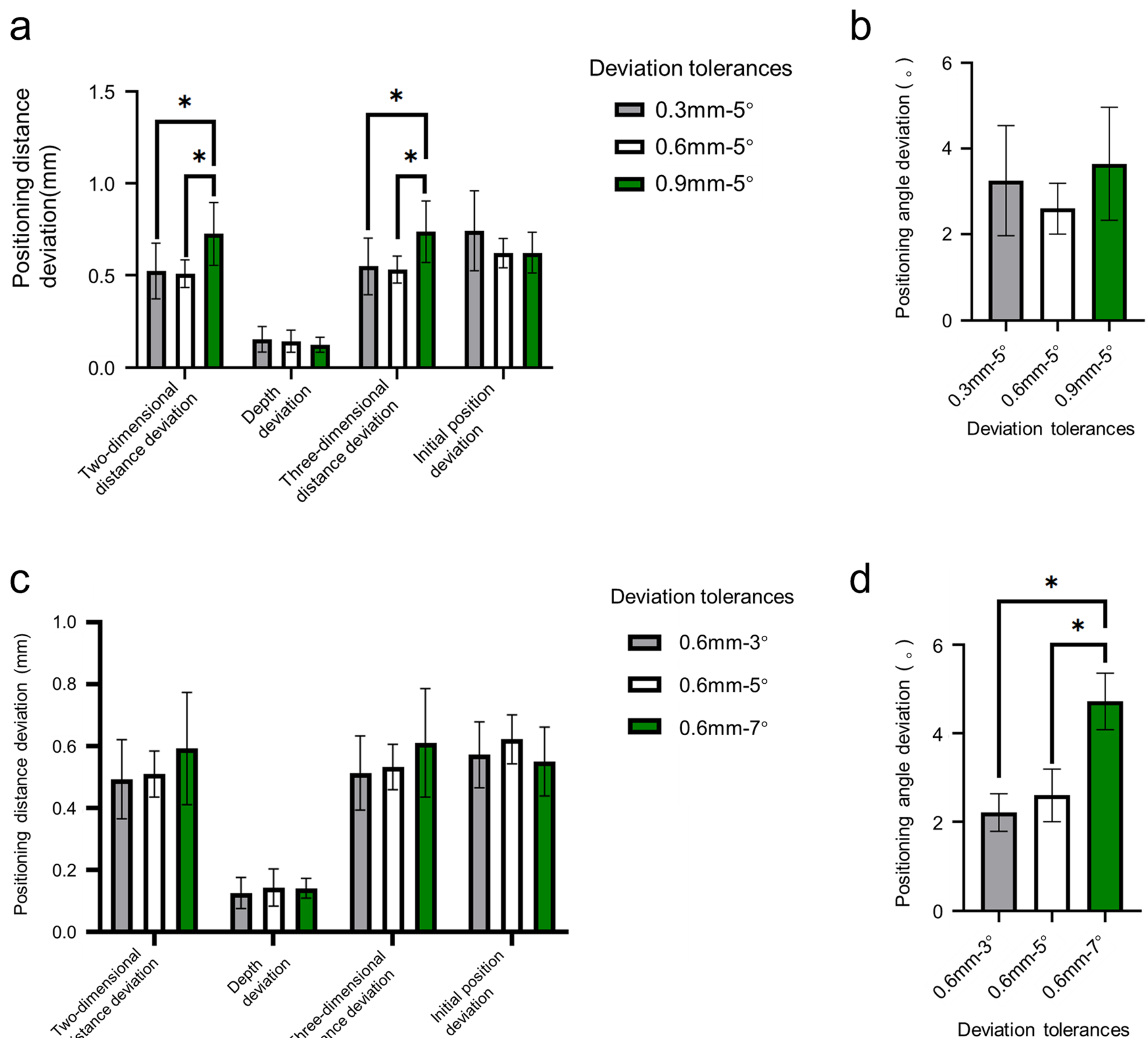


**Fig. 5** Positioning deviation during dynamic navigation using different deviation tolerances. (**a**) Positioning distance deviation using different DDTs; (**b**) Positioning angle deviation using different DDTs; (**c**) Positioning distance deviation using different ADTs; (**d**) Positioning angle deviation using different ADTs. *: The difference between the groups was significant ($P<.01$)

the angle deviations between the groups whose ADT was 5° and 7° ($P < 0.01$). There was no significant difference in the two- or three-dimensional distance deviation, depth deviation, or initial position deviation of dynamic navigation in the positioning accuracy during dynamic navigation among different ADTs ($P > 0.01$).

As the ADT increased, the positioning accuracy during dynamic navigation decreased. Regarding to the ADT of 3° and 5°, positioning during dynamic navigation was highly accurate, with an average three-dimensional distance deviation of only 0.52 ± 0.10 mm and an average positioning angle deviation of only 2.41 ± 0.54°.

## Discussion

The influence of DDTs and ADTs on the positioning accuracy using dynamic navigation in endodontic surgery was evaluated in this study. The first consideration for the model design is the drilling depth, namely, the distance between the hemispherical cavity and the outer surface.

The average depth from the buccal bone plate surface of the first premolar to the completion of root-end removal is 6.01 mm, while the average depth from the buccal bone plate surface of the distal root of the mandibular second molar to the completion of root-end removal is 12.69 mm [31]. Taking into account the anatomical variations of different teeth, a drilling depth of 5 mm to 15 mm can cover that of posterior tooth endodontic surgery [31–33]. It was reported that as the drilling depth increases, the positioning accuracy decreases during dynamic navigation [26]. In the present study, a drilling depth of 15 mm presenting a highly difficult and error-prone scenario was selected for research, which might be more representative for highly difficult clinical situations.

The Objet30 Prime printer was selected to create a model using VeroClear resin in this study [34, 35]. And it has a high printing accuracy of up to 0.1 mm. This reduces the interference of model size deviation on the experimental results.

VeroClear resin was selected as printed model material in this experiment, with a Rockwell hardness of 73–76 HRB, which is an internally homogeneous and dense acrylic resin material. It has a good X-ray resistance difference with the air in the cavity under CBCT imaging, which makes it easier to clearly distinguish the boundary between the model material and the cavity in dynamic navigation software.

Compared with anatomical models, standardized models are considered to replicate experiments and control interference from non-target factors. For instance, they can avoid the influence of root morphology and prevent operation deviations caused by discrepancies between alveolar bone density and root density. This study showed reliable results of the operation during dynamic navigation using the model with VeroClear. Hitherto, resin printed models are widely used in in vitro research. VeroWhite resin-printed jaw and tooth models with similar physical and chemical properties to VeroClear resin materials were used for in vitro endodontic surgery research [36], and model teeth printed with similar resin materials were also used for root canal preparation-related research [37]. However, further research and development are needed to simulate the structure of alveolar bone clinically as much as possible. Due to standardized models and the in vitro nature of the present study, the results cannot be transferred directly to complex clinical situations.

To our knowledge, this is the first study evaluating the relevance of deviation tolerances during dynamic navigation system. Since there is no specific advanced dynamic navigation designed in endodontics, it needs to be completed with the application of implant dynamic navigation software [38]. However, there are allowed larger deviation tolerances in implantology during dynamic navigation. We need to select a smaller range of deviation tolerance to guide the operation in endodontic surgery in order to obtain a high reliability.

The present proof-of-concept suggested that the positioning accuracy during dynamic navigation is closely related to the deviation tolerance selected by the operator. Future studies focusing on dynamic navigation accuracy should first define the settings of ADT and DDT.

Firstly, a deviation tolerance of 0.3 mm/5° was used in this study. It was shown that a DDT of 0.3 mm was more difficult to meet than a ADT of 5°. On the one hand, this study showed that there was no significant difference in the positioning accuracy between the 0.3 mm and 0.6 mm deviation tolerance, while 0.9 mm significantly increased the dynamic navigation deviation. On the other hand, reducing the ADT up to 3° did not improve the positioning accuracy but instead increased the operation difficulty. Increasing the ADT was also not advisable because it significantly increased the angle deviation. In summary, the recommended deviation tolerance of 0.6 mm/5° in the present study ensured highly accurate positioning while reducing the operation difficulty.

Notably, the deviation tolerance is not a recommended deviation value during the operation process but an insurmountable range. If the operation is performed with a 0.6 mm/5° deviation tolerance, it does not mean researchers must maintain it but should always try to minimize the deviation values. The significance of deviation tolerances means to remind the operator early enough to make corrections.

There are reasons for the definition of the deviation tolerance in order to gain a reliable accuracy during dynamic navigation. For the DDT, the results of the present study showed there was no significant difference in positioning deviation between the 0.6 mm and 0.3 mm DDT groups. For a DDT of 0.3 mm, the operator was trying to reduce the deviation from 0.4 mm to 0.3 mm most of the time. There were also situations in which the positioning deviation reached 0.4 ~ 0.5 mm, at which point, the operator needed to stop drilling and try to reduce the deviation. For a DDT of 0.6 mm, the operator can control the deviation at a level of 0.3 ~ 0.5 mm easily and continue to complete the operation. Therefore, the difference of real-time drilling paths between the 0.6 mm and 0.3 mm DDT groups was relatively small. For the DDT of 0.9 mm, the operator may adjust later. During the operation, the real-time deviation displayed was mostly between 0.5 and 0.7 mm, which was significantly different from that of the tolerance groups of 0.3 mm and 0.6 mm.

## Conclusions

Within the limitations of the present in vitro study, a deviation tolerance of 0.6 mm/5° seemed to be suitable for endodontic surgery during dynamic navigation. It improved the operation efficiency and ensured the positioning accuracy. The present study provided recommendations for selecting parameters of deviation tolerance in dynamic navigation in endodontic surgery. It also defined reference values on the positioning accuracy and operation efficiency in dynamic navigated endodontic surgery for in vitro or clinical quantitative research in the future. In addition, the results can be used to develop a specific mode of dynamic navigation in endodontic surgery and might simplify the process of navigation application in endodontic surgery. However, further studies are needed to confirm the feasibility of the recommended DDTs/ADTs in common and complex clinical scenarios.

### Abbreviations

| | |
|---|---|
| 3D | Three dimensional |
| ADT | Angle deviation tolerance |
| CBCT | Cone-beam computed tomography |
| DDT | Distance deviation tolerance |
| STL | Stereolithography |

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Not applicable.

### Authors' contributions
Conception and design of the study were proposed by ZW and XW. The data were acquired by SL and YZ. The data were analyzed by SL and LP. The manuscript was drafted by LP and revised by BH. SL and LP contributed equally to this study. ZW is the corresponding author of this article. All authors have agreed with the final version of the manuscript.

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### Data availability
No datasets were generated or analysed during the current study.

## Declarations

### Ethics approval and consent to participate
Not applicable.

### Consent for publication
Not applicable.

### Competing interests
The authors declare no competing interests.

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