The Guiding Effect of Digital Image Based on Cone-Beam Computed Tomographic on Oval Root Canal Preparation

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Abstract

Background: To evaluate the guiding effect of digital image based on cone-beam computed tomographic in improving the quality of single oval root canal preparation.

Methods: A premolar was selected by CBCT and a 3D-printed root canal model was made. Twenty postgraduates from the Department of Stomatology of Shanghai Ninth People's Hospital were selected to perform root canal preparation on 3D printed oval root canal model teeth. They were randomly assigned to two groups(n=10) according to the guiding method received: CBCT original image (control group) and CBCT-based digital image (experimental group). CBCT scans were performed on the models before and after the guidance. The changes in root canal cleanliness, residual minimum thickness, transportation and over-preparation amount were analyzed.

Results: The experimental group caused significantly more increased amount of cleanliness compared to control group($P<0.05$), 6.0373% ±6.0766% in the control group and 13.7193%±6.7102% in the experimental group. There was no significant difference in the reduction of residual minimum wall thickness between the two groups ($P>0.05$), 0.0154mm±0.2110mm in the control group and 0.0362±0.0444mm in the experimental group. In the control group, the transportation after second preparation was generally increased (increased 0.0084mm on average). In the experimental group, the transportation was generally reduced after second preparation (reduced 0.0081mm on average). But there was no significant difference in the transportation change between the two groups ($P>0.05$). After the second preparation, there was no significant difference in the amount of increased over-preparation between the two groups ($P>0.05$): 1.7029%±3.6622% in the control group and 3.5144%±4.8075% in the experimental group.

Conclusions: Compared with traditional CBCT image guidance, the digital image method can significantly improve the cleaning effect of the oval root canal preparation. It didn't result in more over-preparation and the amount of residual wall thickness was ensured. At the same time, it has a certain effect on reducing transportation after the guidance.

Background

Root canal preparation, as an important step of the cleaning and shaping, was often closely related to the success of root canal therapy (1). However, there has not been an effective and objective method to evaluate the quality of root canal preparation in the clinical. The dentists often judged according to their own experience. There was also a lack of effective guidance methods for the dentists to improve the therapy. At the meantime, it was more challenging to treat the non-circular (e.g. oval, flat) root canal with the existing instruments. For an instance, oval root canals often formed narrow and deep recess on the buccal and lingual side, where the infected substances cannot be effectively cleaned up (2)-(3); it was also easy to cause excessive cutting in the mesial and distal, which can lead to perforation or even fracture of the root canal in severe cases (4). Therefore, it was particularly important to establish an effective evaluation and guidance method for the preparation of oval root canals. No relevant studies have been found so far.

Some scientists tried to create non-destructive method to evaluate root canal preparation, including 2-dimensional image photography and X ray film (5)-(6), but the results were limited. It was hard to reflect real effect of three-dimensional characteristics and root canal preparation. With the development of imaging technology, 3D evaluation based on CBCT and MicroCT has become a research hotspot in recent years (7)–(9). MicroCT had high resolution, but it also had great limitations in terms of measurement methods, time consumption and cost. What's more, it cannot be further applied in clinical practice. While small-field CBCT has been gradually applied to the diagnosis and treatment of pulp diseases and the evaluation of root canal preparation due to its high accuracy and simple operation. Some researchers took several cross-sections of root canals and calculated the area and center point to represent the quality of preparation. Some also intercepted every cross-section of the root canal, but only calculated the distance change of the center from two directions (proximal and distal directions, buccal and lingual directions)(10)–(12). There was still much room to improve in these evaluation methods. In this study, small-field CBCT was adopted to try to establish a new scientific measurement method to improve the accuracy of evaluation.

Digital technology and image reconstruction gradually become the focus in medical research. In stomatology, the rapid development of virtual auxiliary technology, digital periodontal aesthetic treatment, digital dental cavity preparation, digital impression technology (13)–(15) has brought a positive role in promoting the research and application of dental clinical technology. There were only few relevant reports in root canal preparation. This study intends to use CBCT as a digital evaluation method to display the effect of root canal preparation through image reconstruction, so as to guide dentists to improve the therapy.

Extracted teeth and root canal resin modules were constantly used in the past research. The former had great anatomical differences, was unrepeatable, and difficult to collect (9),(16)-(18). The latter is the artificial resin with uniform morphology, which cannot replace the real and complex root canal morphology (19). In recent years, imaging data of extracted teeth was reconstructed to make 3D printed resin tooth models (20)-(23). Such models were derived from real root canal morphology with high consistency, repeatability and high precision, which was conducive to reducing the sample differences in study.

This study intended to use CBCT scanning combined with digital technology and image reconstruction. The effect of root canal preparation can be visually displayed to dentists in image, colors and other ways, which help them observe and analyze the specific location and extent of insufficient preparation. The main purpose was to study whether this method can guide dentists to improve the current effect of root canal preparation. It might provide a certain research basis for immediate evaluation of the quality of root canal preparation in future clinical practice, so as to guide dentists to perfect root canal treatment and improve the prognosis of infected teeth.

Methods

1. 3D-printed root canal tooth model

Extracted human premolars without root canal treatment were collected, which was approved by the Scientific Research Projects Approval Determination of Independent Ethics Committee of Shanghai Ninth People’s Hospital affiliated with Shanghai Jiao Tong University (ethical approval document No. 2017-399-T296). All methods were performed in accordance with the relevant guidelines and regulation. The residual calculus and soft tissues were cleaned and the teeth were stored with normal saline. After drying, the canal anatomy was checked by CBCT scan (Scanora 3Dx, Soredex, Tuusula, Finland). According to the results, a suitable tooth was selected: a single oval root canal, canal curvature of 0°, root length of 21.5mm (from physiological apical foramina to buccal cusp). The long axis and short axis of the oval cross section of the root canal were 2.1712mm and 1.2763mm at the root canal orifice, 1.4454mm and 0.8337mm at the middle of the root canal, 0.4658mm and 0.4599mm of 4mm from the apical. The DICOM data of the tooth were processed by Mimics software. Then the 3Dimage was constructed and the STL format was output.

The tooth model was further designed with the pulp opening and anchor points. The STL format was printed by a high-precision 3D printer Projet 3500 HDMAX (3D System, South Carolina, America) with the Visijet M3 Crystal resin material (3D Systems, South Carolina, America).(Figure 1)

2. Root canal preparation

Before the preparation, the CBCT scan of the origin 3D-printed root canal model was performed to save the data for comparison of the effect before and after the preparation in the subsequent procedures. The root canal model was fixed into the vice. Each operator prepared one 3D-printed tooth model. Firstly, the 10# K file and 15# K file were used to dredge 2/3 of the root canal. Then, the SX file of ProTaper nickel-titanium file system (Densply) was used to prepare the 2/3 of the root canal according to the manufacturer's recommended process. 10# or 15#K file was inserted again to reach the working length (21.5mm, anchor point: buccal cusp). Then S1, S2, F1, F2, F3 file were used in turn. The operator can choose the major apice file according to their own judgment. Each time before changing the nickel-titanium, the root canal was rinsed by lateral opening needle with distilled water and rinsing amount >2ML. The K file was used again for dredging and H file was used for further debris cleaning if necessary. After preparation, the debris was cleaned again and the root canals were thoroughly rinsed with the amount of >5 ml. The root canal was dried with absorbent point and the model was removed from the vice.

3. Groups

20 postgraduates from the Department of Stomatology of Shanghai Ninth People's Hospital were randomly divided into two groups according to the two different guidance methods. There were 10

students in each group. One root canal tooth model was prepared by each student and the second preparation was performed under two different guidance methods.

Experimental group: CBCT based image guidance method

The DICOM data of the root canal tooth models before and after preparation of the experimental group were imported into Materialise Mimics V19.0 software. 3D reconstruction was performed by Geomagic Studio2013 software for measurement and analysis. A comparison figure of the reconstruction before and after first preparation was showed for the operator's reference for 5minutes (Figure. 2). Then, according to the guidance, the root canal tooth models were prepared for the second time until the operator thought that the preparation was complete. Then rinsing and drying were done before preservation.

Control group: CBCT original image guidance method

The CBCT original image of the 3D printed models before and after root canal preparation was presented in the computer system of the Department of Endodontics in Shanghai Ninth People's Hospital. The operators could only view the cross-sections (Figure 3) because of the limitation of the hospital computer system software. The operators could drag the cursor up and down on the screen to observe all levels from the crown to the apical. The time limit was 5 minutes. According to CBCT original image, the root canal tooth model was prepared for a second time until the operator thought that the preparation was complete. Then rinsing and drying were done before preservation.

4. CBCT scanning and image processing

The prepared root canal tooth models were fixed on the device and scanned by CBCT (Scanora 3DX, Soredex, Tuusula, Finland) with the x-ray parameters of 90kV and 10mA. The layer thickness was 0.1mm with a small field of vision of 50mm×50mm. The data of each one was successively imported into Materialise Mimics V19.0 software for 3D reconstruction and STL format was output. After imported into Geomagic Studio2013 software, the comparison with the reconstruction of the original root canal tooth model before preparation was made. The following four indexes were measured and analyzed:

Root canal cleanliness：

When the cutting thickness of the root canal wall of the 3D printed root canal tooth model was ≥ 75μm, it was considered as the effective cleaning area. According to this criterion, the root canal wall was divided into two areas: uncleaned and effectively cleaned areas. Root canal cleanliness referred to the ratio of effectively cleaned area to the total area of the root canal wall.

Root canal transportation：

In any section of the root canal, the maximum distance of the geometric central axis before and after preparation was represented as root canal transportation.

Residual minimum root thickness

Within the effective measurement range (from the root canal orifice to 1mm from the apical), the minimum distance between any point on the root canal wall and any point on the outer surface of the root was represented as the residual minimum root thickness.

Over-preparation amount

When the cutting thickness of the root canal wall of the 3D-printed root canal tooth model was ≥ 200μm, it was considered as the over-prepared area. According to this criterion, the root canal wall was divided into two areas: unprepared and overprepared areas. Over-preparation amount referred to the ratio of the overprepared area to the total area of the root canal wall.

5. Statistical analysis

After the second root canal preparation, CBCT scanning was performed again and reconstruction was analyzed to obtain the results of second preparation effect. For the results analysis, the independent sample t-test was used. The level of significance was set at 0.05, and IBM SPSS Statistic version 25 was used. The calculation of the data of first and second preparation in the two groups was made to analyse whether there was a statistical difference in the improvement of the root canal preparation between the two groups.

Results

In terms of cleanliness, the improved amount of the experimental group (13.7194%±6.7102%) was significantly higher than control group (6.0373%±5.0766%), $P < 0.05$.

In terms of the minimum wall thickness, the reduced amount had no significant difference between the experimental group (0.0362mm ± 0.0444mm) and the control group (0.0154mm ± 0.0211mm), $P > 0.05$. There was also no significant difference in the increased over-preparation amount between the experimental group (3.5144%±4.8075%) and the control group (1.7029%±3.6622%), $P > 0.05$. (Table 1)

Table 1
the variation of cleanliness, residual minimum root thickness, transportation and over-preparation amount after two times root canal preparation with two different guidance methods

	Control group (n = 10)	**Experimental group(n = 10)**	**P value**
	$\bar{x}$ ± s	**$\bar{x}$ ± s**	
Increased cleanliness(%,2nd -1st)	6.0373 ± 5.0766	13.7194 ± 6.7102	0.010
Reduced residual minimum root thickness(mm,2nd -1st)	0.0154 ± 0.0211	0.0362 ± 0.0444	0.197
Changed amount of transportation(mm,2nd -1st)	0.0084 ± 0.0194	-0.0081 ± 0.0233	0.102
Increased over-preparation amount(%,2nd -1st)	1.7029 ± 3.6622	3.5144 ± 4.8075	0.356

In terms of transportation, the average changed amount after the first canal preparation was 0.1158mm ± 0.0459mm and 0.1242mm ± 0.0493mm after the second canal preparation in control group. According to the pair t-test, there were significant difference ($P = 0.045 < 0.05$). In the experimental group, the average changed amount after the first root canal preparation was 0.1274mm ± 0.0265mm and 0.1193mm ± 0.0285mm after the second root canal preparation. According to the pair t-test, there were significant difference ($P = 0.000 < 0.05$). The results showed that the transportation of the control group was significantly increased with traditional CBCT original image guidance. While the transportation of the experimental group was significantly reduced by digital image guidance. (Table 2)

Table 2
the transportation after two times preparation of the root canal tooth models with two guidance methods

		$\bar{x}$ ± s(mm)	**P value**
Control group(N = 10)	After first preparation	0.1158 ± 0.0459	0.045
	After second preparation	0.1242 ± 0.0493	
Experimental group(N = 10)	After first preparation	0.1274 ± 0.0265	0.000
	After second preparation	0.1193 ± 0.0285	

Discussion

For the research of the root canal preparation, it was very important to select the proper subjects. In general, the human extrated teeth (16)-(18) were commonly used. Although they were able to reflect the real clinical situation, it was nearly impossible to avoid the differences in each tooth, which may affect the experimental results (24). Guimaraes(9) reduced the differences among root canals of human extracted teeth by selecting paired contralateral teeth from the same patient, which greatly increased the difficulty of the study and the effect had limitation. Other studies used resin blocks (25)-(26), but they did not reflect the complexity and diversity of root canal morphology(27)-(28). In recent years, more and more scholars have devoted themselves to the 3D printed models by using digital technology. Kha-Lil(29) and Lee(23) compared the 3D printed tooth models with the corresponding human extracted teeth and concluded that the 3D printed models could truly reflect the anatomical morphology of the human teeth.

Cui(21)et al. used 3D printed root canal tooth models to study the shaping ability of PTN and WaveOne nickel-titanium file systems. The root canal tooth model was confirmed with high accuracy and repeatability, which makes the experimental conclusion more reliable. It also laid a foundation for further research in clinical practice.

Different from the previous production process of the model, the small-field CBCT were used to replace the MicroCT. The process was more convenient while maintaining the accuracy. In addition, since the oval root canal, as a special cross-sectional shape of the root canal, has attracted much attention in the research of root canal preparation, which often reflects the preparation characteristics, advantages and disadvantages of different operators, instruments and preparation methods. In this study, a proper human oval root canal premolar was selected to make the corresponding 3D printed root canal tooth model.

In order to establish a straight path, Eken(30) cut the crown of root canal tooth models before the preparation to ensure the consistency. In this study, after 3D reconstruction of the original data, the access cavity was designed to ensure consistency. At the same time, hemispherical anchor points were added to the crown and root of the model to improve the accuracy of matching and measurement.

20 postgraduates from the Shanghai Ninth People's Hospital have already received systematic education of oral theory and standardized practice of root canal therapy skills. SPSS software was applied to the randomized block design. The results of the first root canal preparation of the two group were represented in Table 3. There was no significant difference in cleanliness, residual minimum root thickness, transportation and over-preparation amount between the two groups ($P > 0.05$), indicating that the initial clinical skills of the two groups were similar.

Table 3
the first root canal preparation result of two groups

	Control group	Experimental group	P value
	$\bar{x} \pm s$	$\bar{x} \pm s$	
cleanliness(%)	49.9799 ± 13.4657	57.4810 ± 8.6013	0.155
Residual minimum root thickness(mm)	0.7353 ± 0.0644	0.7426 ± 0.0432	0.769
transportation(mm)	0.1117 ± 0.0449	0.1274 ± 0.0265	0.355
Over-preparation amount(%)	2.1590 ± 3.5957	0.9274 ± 1.4079	0.334

The quality of root canal preparation was mainly reflected in the cleaning and shaping effect. Therefore, small-field CBCT combined with digital technology was used to evaluate the preparation effect of the root canal from four indexes: cleanliness, residual minimum root thickness, transportation and over-preparation amount. The measurement method of each index was further optimized. The analyzed CBCT data in this study included every section and every direction of the root canal, which maked up for the shortcomings of previous reports that only included several sections of the root canal for analysis (10)-(12). What's more, small field CBCT scanning provided the possibility for further clinical application compared with MicroCT scanning.

The results showed that the cleanliness of the two groups had been improved to a certain extent through guidance. The improvement effect was better under the guidance of digital image method. As represented in Fig. 4, the cleanliness of the first root canal preparation was 59.42%. The cleanliness of second preparation was 78.74% after the digital image guidance. The increased amount was 19.21%. The undergraduates of experimental group could directly observe the unprepared area of the root canal wall through digital image guidance (the area marked blue and green color, Fig. 2), so as to strengthen the preparation and debris washing in the certain area. However, the traditional CBCT original image guidance method required human eyes' observation, which was time-consuming and complex. Many differences were difficult to be identified by the naked eye, and the overall effect was difficult to grasp. So it was hard to give clear instructions to the control group. Thus CBCT-based digital image guidance could effectively improve the cleanliness of oval root canal preparation.

In the first preparation results of the two groups, the unprepared areas of the root canal wall were mainly concentrated in the middle 1/3 and apical 1/3 part of the lingual wall, the crown 1/3 and middle 1/3 part of the buccal wall (Fig. 4). The results after the second preparation showed that the green part of the area was effectively reduced through digital image guidance, but no one could completely eliminate the whole green part of the area, which meant the cleanliness could not reach 100%. This outcome was closely related to the oval shape of the root canal cross section of the model. In clinical, the high incidence of oval root canals (the largest diameter to the smallest diameter of the root canal cross-section was greater than 1) (31)-(33) tended to form a narrow and deep recess on the buccal and lingual side. Root canal preparation with traditional nickel-titanium instruments was limited to its circular cross-section and hard to clear infection on buccal and lingual wall (2)-(3). On the other hand, there was a longitudinal recess on the coronal part of the buccal side in this model. It was difficult for instruments to adapt the root canal wall, which was not conducive to effective preparation, resulting in poor cleanliness in the 1/2–2/3 part of buccal wall (Fig. 1A). It is suggested that effective root canal irrigation should also be applied to oval root canal besides paying attention to the cutting effect of the instrument.

While the mesial and distal walls of the oval root canal are relatively thin. In clinical, there was often excessive instrument in the mesial and distal directions, which was easy to cause tooth fracture. The results of this study also showed that the over-preparation area was more common in the mesial and distal root canal walls (Fig. 4).

In terms of the changed amount of transportation, there was no significant difference between the two groups. However, the transportation was increased after the traditional CBCT original image guidance and generally decreased after the digital image guidance. It indicated that digital image guidance method had a certain guiding significance for reducing the root canal deviation and maintaining the original anatomy of the root canal. The transportation was often related to the curvature of the canal. In general speaking, the greater the curvature of the canal, the more likely it was to cause transportation (34). Since the curvature of model was 0°in this study, the preparation was not so technically sensitive. Thus it may caused no significant difference between the two groups($P > 0.05$). Different degree of curvature of tooth models could be used in the further study of the guidance effect in transportation.

By digitizing and analyzing CBCT data before and after root canal preparation, the digital image guidance could provide dentists with intuitive analysis and guide dentists to improve preparation accurately and effectively. It could also be applied to the exploration and guidance of difficult root canal preparation in other features of teeth, which has important guiding significance for clinic and lay a research foundation for clinical root canal preparation and guidance methods.

Conclusions

Compared with traditional CBCT image guidance, the digital image method can significantly improve the cleaning effect of the oval root canal preparation. It didn't result in significantly more over-preparation and the amount of residual wall thickness was ensured. At the same time, it has a certain effect on reducing transportation after the guidance.

Abbreviations

CBCT: Cone-beam computed tomography; MicroCT: micro-computed tomography

Declarations

Acknowledgements

Not applicable.

Authors' contributions

YW, WX and TZ developed the design of this study. YW and XB performed the experiment. HL, MD and LZ supervised the data assessment. YZ and ZQ performed statistical analyses, and all authors contributed to the interpretation of the data. YW and ZQ drafted the manuscript. All authors read and approved the final manuscript.

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study and collection, analysis, and interpretation of data.

Availability of data and materials

The dataset used during the study are available from the corresponding author upon request.

Ethics approval and consent to participate

All procedures will be carried out in compliance with the Helsinki Declaration.

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This study was approved by the Scientific Research Projects Approval Determination of Independent Ethics Committee of Shanghai Ninth People's Hospital affiliated with Shanghai Jiao Tong University (ethical approval document No. 2017-399-T296). All procedures will be carried out in compliance with the Helsinki Declaration. Informed consent was obtained from all subjects or their legal guardians.

Consent for publication

Not applicable.

Competing interests

Not applicable.

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Figures

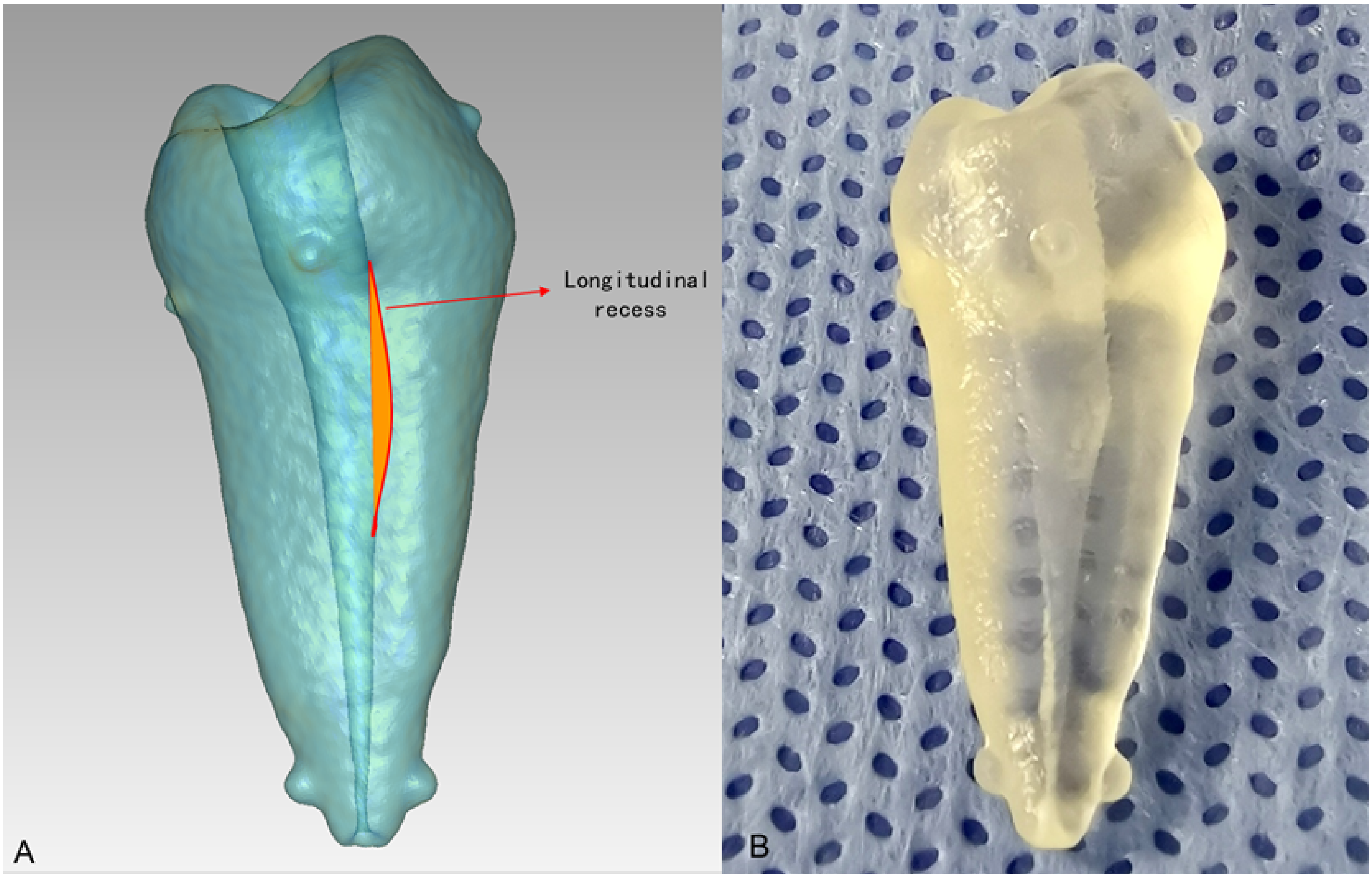

Figure 1

A：longitudinal recess on the buccal side of the 3D printed root canal tooth model (orange area). B: Root canal tooth model

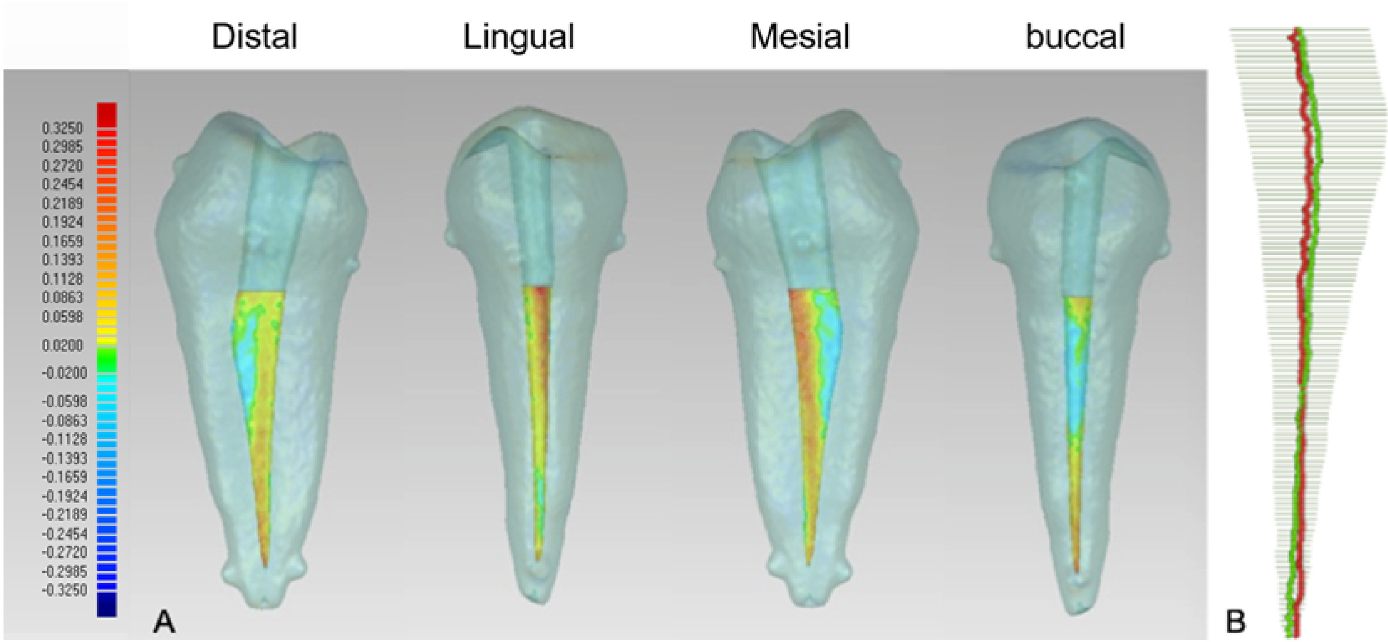

Figure 2

Comparison figure of CBCT-based digital image guidance method A: The depth of the instrumented root canal wall was marked by different colors: The red area indicated the area of the depth≥200μm, which was named the over-preparation area. The yellow area indicated the area of 75μm≤ depth < 200μm, which was named the proper preparation area; Green and blue area indicated the depth ≤ 75μm, which was named insufficient preparation area. B: Relationship between the central axis of the root canal before and after root canal preparation. Green line indicated the geometric central axis of the root canal before preparation; red line indicated the geometric central axis of the root canal after preparation.

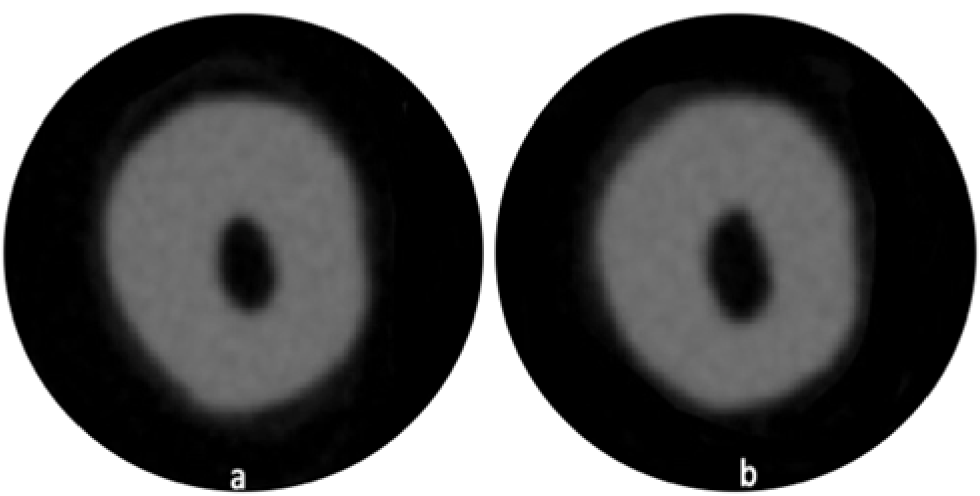

Figure 3

The CBCT original image of the 3D printed models before and after root canal preparation in control group (a)before preparation (b)after preparation.

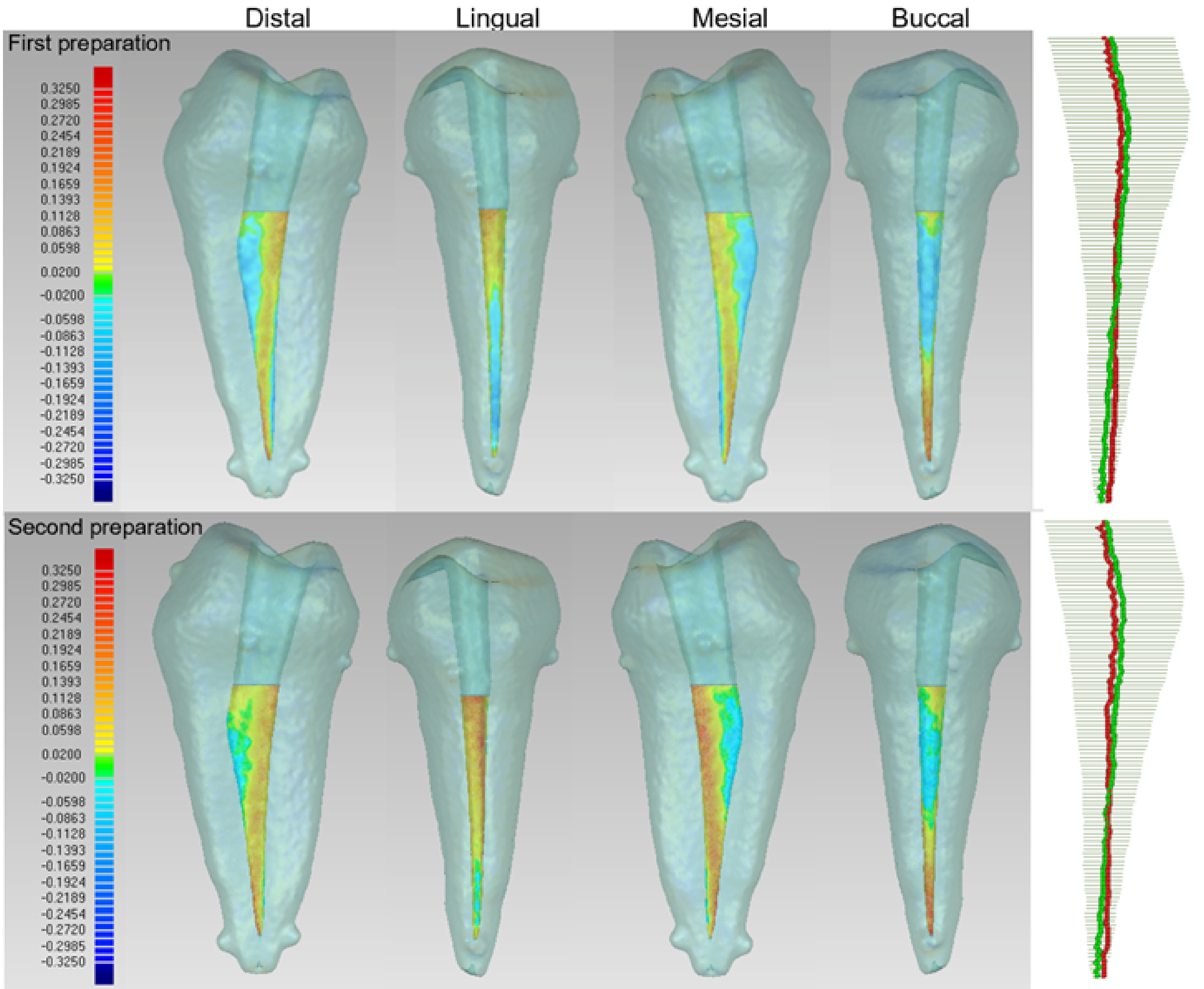

Figure 4

3D reconstruction image of the cleanliness and transportation after first and second preparation in experimental group