

Establishment of narrow root fracture models using modified temperature cycling method and diagnosis using different cone-beam CT units

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Research article

Keywords: cone-beam CT, diagnosis, fracture line, modified temperature cycling

Posted Date: November 2nd, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-97389/v1>

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Abstract

Aim

Using modified thermal cycling method to establish narrow root fracture models and evaluate the diagnosis efficiency of them using four different cone-beam CT (CBCT) units.

Methodology

Fifty-six intact teeth were selected and the crowns of the teeth were embedded using general purpose acrylic resin. 50 VRF models were established by soaking these teeth in liquid nitrogen and hot water cyclically; 6 teeth were used as negative control. All the 56 teeth were scanned with the smallest voxel size of four different CBCT units (NewTom VGi, Planmeca Promax 3D Max, Kavo 3D eXam and Soredex Scanora3D). The CBCT images were evaluated for the presence or absence of fracture lines. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and area under the receiver operating characteristic curve (AUC) were calculated for the diagnosis of FLs using the four CBCT units. After that, 10 VRF teeth were randomly selected and the roots were sliced using slow-speed saw to obtain horizontal root sections with thickness of 2mm from enamel-cemental junction to the root apex and 25 root sections were finally obtained. Scanning electron microscope (SEM) was used to measure the width of the fracture lines (FLs) for each root section at one side.

Results

Fifty narrow root fracture models were successfully established. There were totally 50 positive VRF models with 83 FLs and 6 negative VRF models. The diagnosis sensitivity was 0.24, 0.38, 0.29 and 0.19, the diagnosis specificity was 0.45, 0.16, 0.55, and 0.75, and the AUC was 0.60, 0.52, 0.59 and 0.61 for NewTom VGi, Planmeca Promax 3D Max, Soredex Scanora-3D and Kavo 3D eXam respectively. Randomly selected 10 models were sliced and 25 root sections with 45 FLs were acquired. The width of FLs was from 3.43 μ m to 143 μ m; 32.06% were less than 25 μ m, only 9.6% were from 75 to 150 μ m with SEM.

Conclusions

The modified temperature cycling method is a simple and effective method to establish narrow root fracture models, the diagnosis efficiency for these narrow fracture lines were quite poor using all the four different CBCT units.

Introduction

Root fracture is defined as a fracture of a tooth that involves the dentin, cementum, and pulp and they may occur in any direction or orientation[1]. X-ray films enabled clinicians to visualize the roots which are surrounded by alveolar bone, therefore provide important information for the diagnosis of root fractures and treatment planning. However, the conventional 2-dimensional X-ray films often could not give a

definite diagnosis in clinical practice due to its disadvantages such as magnification, distortion and anatomic superimposition[2, 3]. The recently widely used CBCT, due to its three-dimensional presentation of teeth with high spatial resolution, enhanced the accuracy of diagnosis of root fractures significantly and being paid much attention to[4–8]. Although CBCT offers clear advantages over conventional X-ray films for the diagnosis of root fractures, the use of CBCT for the detection of root fractures remains controversial[9–11]. The complexity of fracture lines and the difference of CBCT units used in clinic are two important factors[12–14]. It's known that the ease of diagnosis will vary according to the extent of the fracture, the detection of incomplete fractures and hairline-like fractures without obvious separation of the fractured fragments could be more difficult than obvious displaced root fractures[10, 14]. And different CBCT units have different voxel size, radiation dose and reconstruction algorithm, these all may influence the quality of CBCT images and the diagnosis. To explore the influence of these two factors and establish a proper protocol of usage CBCT in clinic, many *in vitro* researches were performed[14, 15]. And the establishment of an artificial root fracture model with similar distribution with nature ones is the foundation of these researches. Mechanical methods were used to establish artificial VRF models in most previous studies[10, 14, 15], the width of the fracture lines in those studies were uniform and much wider than the nature ones, especially wider than the ones at the initial stage.

The aim of this study was mainly 2-fold: firstly we modified the thermal cycling method to establish narrow root fracture models which are more similar with the nature ones at the initial stage in clinic; secondly, compared the diagnosis efficiency of four different CBCT units with the smallest voxel size for these narrow root fracture lines.

Materials And Methods

Objectives

Fifty-six intact teeth were extracted with minimally invasive extraction due to orthodontic treatment plan or periodontal diseases at the Nanjing Stomatological Hospital, Medical School of Nanjing University. The inclusion criteria were no visual evidence of external cracks, craze lines, or fracture with the naked eye following extraction. The exclusion criteria were the presence of dental caries, root absorption, severe abrasion, wedge-shaped defects, and horizontal or vertical root fractures. This study was approved by the Ethics Committee of Nanjing Stomatological Hospital, Medical School of Nanjing University.

Establishment of artificial vertical root fracture model

All 56 freshly extracted teeth were immediately immersed in saline solution (0.9% isotonic NaCl). Before establishing *in vitro* artificial root fracture models, the crowns of the teeth were embedded with general purpose acrylic resin (Unifast Trad, GC Corporation, Tokyo, Japan). Thereafter, 50 teeth were soaked in 100°C hot water for 1 min and then were quickly transferred into liquid nitrogen (-196°C) for 1 min, this procedure was repeated once there was one or more FLs was observed on the surface of the root of the teeth with naked eyes. All the 50 teeth were finally confirmed were positive root fracture models with the dental operating microscope (Carl Zeiss Meditec AG, S100/OPMI pico, Jena, Germany).

CBCT image acquisition and evaluation

The 56 teeth were numbered and located on a piece of polystyrene foam and then scanned using the smallest voxel size of four different CBCT units (NewTom VGi, Planmeca Promax 3D Max, Kavo 3D eXam and Soredex Scanora-3D). The details of the four CBCT units were showed in Table 1.

The CBCT images were viewed on a 29.7-in. screen MX300W LCD monitor (EizoNanao Corporation, Japan) and analyzed with inbuilt CBCT image analysis software of each unit (Planmeca Romexis Viewer for Planmeca Promax 3D Max, NNT Viewer for NewTom VGi, eXam Vision for Kavo 3D eXam and OnDemand3D APP for Soredex Scanora3D).

Two observers (a radiological graduate student, an experienced radiologist) evaluated all images independently. If there was a hypodense line on axial images of teeth in at least 2 consecutive slices, the tooth was diagnosed as positive one. If a consensus could not be reached between the two examiners, a senior radiologist assisted in making the final decision. Before evaluation, calibration, including unified training on diagnostic standards of fracture line was performed. After one week, the observers assessed all the images again to analyze the intra-examiner agreement.

Sample preparation

Acquirement of root sections with FLs

10 artificial root fracture teeth were randomly selected and stabilized in square mold filled with general purpose acrylic resin (Unifast Trad, GC Corporation, Tokyo, Japan) to embed the root of the teeth. Horizontal root sections with thickness of 2mm were acquired from enamel-cemental junction to the apex of root using a slow-speed saw (Isomet, Buehler, Lake Bluff, IL, USA) under water cooling. Samples without visible fracture lines as well as complete fragmented were excluded. The process is shown in the Figure 1. This procedure resulted in 25 root sections. All the 25 sections were numbered and marked so facial, lingual, coronal, apical sides could be identified. During all subsequent procedures, the sections were either stored in water or kept moist to prevent preparation shrinkage fracture or crack from dehydration.

Measurement of width of FLs using SEM

The digitized images of the surface of each root section were captured with a magnification of 50x, 500x or 1000x using a scanning electron microscope (SEM, S-3400N-II Hitachi Tokyo Japan). For each root section, the width of FLs was measured at coronal side. Widths of FLs were measured at three points (S1, S2, and S3), S1 was near to root canal, S3 was in the outer cementum surface, and S2 was the middle point of S1 and S3 (Fig. 2). These processes were operated by one operator in order to ensure the consistence of the measurements.

Statistical analysis

Statistical analysis was conducted using the SPSS 22.0 software (IBM SPSS Statistics Base Integrated Edition 22, Armonk, NY, USA). The distribution of the FLs was analyzed. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were assessed. To determine the diagnostic abilities of the four CBCT units, receiver operating characteristic (ROC) curves were constructed and the areas under the ROC curve (AUC) were analyzed. Kappa analysis was used to assess inter- and intra-examiner agreement.

Results

Twenty-five root sections with 45 FLs were acquired, and 135 points were selected and measured. The distribution of width of FLs was shown in Table 2. The widths of FLs were from 3.43 μm to 143 μm . 14.1% points had width under 10 μm , while 28.1% points had width between 10–25 μm , 9.6% were from 75 to 150 μm . 10 of 45 FLs were S1 wider than S3, while the others were the opposite. 50 positive VRF models with 83 FLs and 6 negative VRF models were scanned with four different CBCT units. Sensitivity, specificity, PPV, NPV and AUC of the four CBCT units were shown in Table 3. All the four CBCT units showed poor diagnosis efficiency. The highest sensitivity was 0.38 which was obtained with Planmeca Promax 3D Max, and the highest specificity was 0.75 which was obtained with Kavo 3D eXam. The biggest AUC was 0.61 which was obtained with Kavo 3D eXam. There was low inter- and intra-examiner agreement for the diagnosis and the results were shown in Table 4.

Discussion

The diagnosis of root fracture can be extremely challenging in clinical practice. Because of the concealed location and atypical early symptoms, its exact diagnosis or prediction commonly requires abundant of clinical experience and fine radiographic presentation. CBCT has been widely used in recent years for the detection of root fractures with relatively high accuracy and sensitivity benefit from its 3-dimensional image compared with 2-dimensional X-ray films [6, 16, 17]. However, the diagnosis of root fractures using CBCT was also controversial due to so many influenced factors existing (different width and direction of fracture line, variables of CBCT units) [3, 9, 18]. To explore a more reliable and proper standard for using CBCT to diagnosis root fractures, many *in vitro* studies were carried out [5, 12, 15]. And to establish an artificial root fracture model similar with the natural ones is the foundation of these studies.

There were two confusing concepts: crack and fracture. According to Rivera's review, the term 'crack' implies an incomplete break in a substance. The term 'fracture' implies a complete or incomplete break in a substance [19]. This means the crack lines could be narrower than fracture lines. And the fracture lines in the initial stage could be much narrower than those in the later stage. Therefore, the diagnosis of cracks or initial fractures could be more difficult than the diagnosis of later fractures.

There were mainly two categories of methods to produce crack or fracture lines in teeth: mechanical method and temperature control method. Mechanical methods were more commonly used to establish root fractures model. In Brady et al' study, incomplete and complete vertical root fractures were induced

by inserting a sewing needle into the prepared canal and applying forces on the needle[10]. Makeeva et al. inserted posts into the root canal and gently tapped with a hammer to induce vertical root fractures[15]. Guo et al. produced vertical root fractures model by cutting the teeth using a diamond wire saw machine[14]. Lloyd et al. was firstly used the thermal cycling method to produce cracks in teeth by using a thermal cycling apparatus allowing teeth cycled between hot and cold streams of water[20]. Wang et al. created cracks by exposure teeth into liquid nitrogen after hot water at 100 °C[21]. In this study, artificial root fracture models were established by modified thermal cycling method. The teeth were soaked in liquid nitrogen and hot water cyclically after their crowns were embedded with acrylic resin, this method avoids the teeth splitting completely and produced quite narrow fracture lines on the surface of the root.

The width of fracture lines produced by mechanical methods in previous study seems to be wider. In Makeeva et al. study, the width of the fracture lines ranged from 20 to 300, the mean width of fractures in the group 50–150 µm was 96.3 ± 40.6 µm, while for the group > 150 µm the value was 230 ± 45 µm, respectively[15]. In Guo's study, the width was 189–376 µm for the wide group and 110–170 µm for the narrow group, the mean width 279.5 ± 53.6 µm and 140 ± 26.8 µm, respectively[14]. However, in clinical practice, the width of fracture lines, especially for initial ones, is narrower than fracture lines induced by mechanical method. Huang et al. collected 37 extracted root fracture teeth and the width of fracture lines was between 10-1070 µm (21.62% points was under 50 µm)[16]. Our study established fracture lines with width between 3.43 µm to 143 µm; and 14.1% points was under 10 µm, 28.1% points was between 10–25 µm. This was much narrower than the fracture lines induced by mechanical methods and could simulate the initial stage of fractures.

In this study, although the smallest voxel size was used, the diagnosis efficiency for these narrow FLs was still quite poor. The biggest AUC was only 0.61, which was much lower than the previous studies [3, 7, 22]. Planmeca Promax 3D Max had the highest sensitivity(0.38), which meant it had the highest capability of detecting VRFs. Kavo 3D eXam had the highest specificity (0.75), which meant it had the highest capability of detecting no VRFs. However, both the sensitivity and specificity was not satisfactory.

It's known that endodontic fillings may cause artifacts that seriously impair the quality of CBCT images[22, 23]. The accuracy of diagnosis of VRFs in endodontics treated teeth could be much lower than non-endodontic treatment teeth[23]. In this study, the fracture lines of our models were quite narrow and the sensitivity, specificity, PPV, NPV and AUC of diagnosis had been quite low. So we did not further have our teeth endodontic treated. And the scanning was performed without much simulation the clinical condition (e.g., fixing teeth in sockets of dry human mandibles). In clinic settings, the effect of surrounding tissues[24] and motion artifacts[25] could influence the quality of CBCT images. Therefore, *in vivo* detection endodontically filled teeth with narrow FLs could be much more difficult.

The width of most fracture lines was much lower than the voxel size of CBCT should be the main reason of the low diagnosis efficiency in this study. For narrow root fractures, the current CBCT units still have

great limitation in the diagnosis (Fig. 3). Therefore, it is possible that some root fractures may not be diagnosed at the time of initial because the fractures are quite narrow.

Moreover, the fracture lines in our study were not consistent and uniform at different points which were showed by SEM. This inconsistency at different points was similar with the condition in clinic, fracture lines of 37 extracted VRF teeth showed inconsistent fracture space in Huang's study[16]. This phenomenon indicated that the relationship between the width of FLs and voxel size of CBCT is more complicated than we assumed. If the FLs are much wider than the voxel size of CBCT, the detection of FLs could be of course easy, but if the width of FLs is close to or narrower than the voxel size, the condition could be sophisticated. The FL might be detected due to the wide part of it and the FL may be presented as blurred and ambiguous on CBCT images.

Conclusions

In this study, we modified thermal cycling method to establish artificial root fracture models. These fractures are quite narrow and had variable width at different points, which may be more similar with the initial condition of fractures. The four CBCT units used in this study had poor diagnosis efficiency for these narrow fracture lines.

Abbreviations

CBCT: Cone-beam CT; SEM:Scanning electron microscope; FLs:Fracture lines; PPV:Positive prediction value; NPV:Negative prediction value; ROC:Receiver operating characteristic; AUC:Area under the receiver operating characteristic curve

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Nanjing Stomatological Hospital, Medical School of Nanjing University (2015NL-044(KS)). Informed consent was obtained from all participants.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This work was supported by the Second Level Fund for the Young Talents in the Health Field of Nanjing City (QRX17079).

Authors' contributions

All the authors made substantial contributions to the present study. JHL & TMW wrote the manuscript; DTC, YC & JHL carried out the experiment; XX, ATG & SP analyzed the data and interpreted the results; ZYW collected and selected the extracted teeth; ZTL contributed the concept and design of this study. All authors read and approved the final manuscript.

Acknowledgments

Not applicable.

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Tables

Table 1 Exposure parameters of four CBCT units

CBCT units	FOV(cm)	Voxel size(µm)	Tube voltage(kVp)	Tube current(mA)	Scan time(s)
NewTom VGi	5*5	100	110	7.48	6
Planmeca Promax 3D Max	5*5	100	80	6.3	12.1
Soredex Scanora3D	5*5	100	90	10	13.6
Kavo 3D eXam	8*8	125	120		5

Table 2
Distribution of width of FLs using SEM

	Width of fracture lines(µm)					
	< 10	10–25	25–50	50–75	75–125	125–150
No. of points	19	38	45	20	12	1
Frequency (%)	14.1	28.1	33.3	14.9	8.9	0.7

Table 3
Sensitivity, specificity, PPV, NPV and AUC of the four CBCT units

	NewTom	Planmeca	Soredex	Kavo
Sensitivity	0.24	0.38	0.29	0.19
Specificity	0.45	0.16	0.55	0.75
PPV	0.65	0.47	0.72	0.82
NPV	0.13	0.12	0.16	0.13
AUC	0.60	0.52	0.59	0.61
PPV: positive predictive value, NPV: negative predictive value, AUC: area under the ROC curve				

Table 4
The reliability of the 2 examiners with regard to VRF detection

	Intra-observer Kappa	Inter-observer Kappa
NewTom	0.509	0.283
Planmeca	0.751	0.106
Soredex	0.509	0.211
Kavo	0.559	0.316

Figures

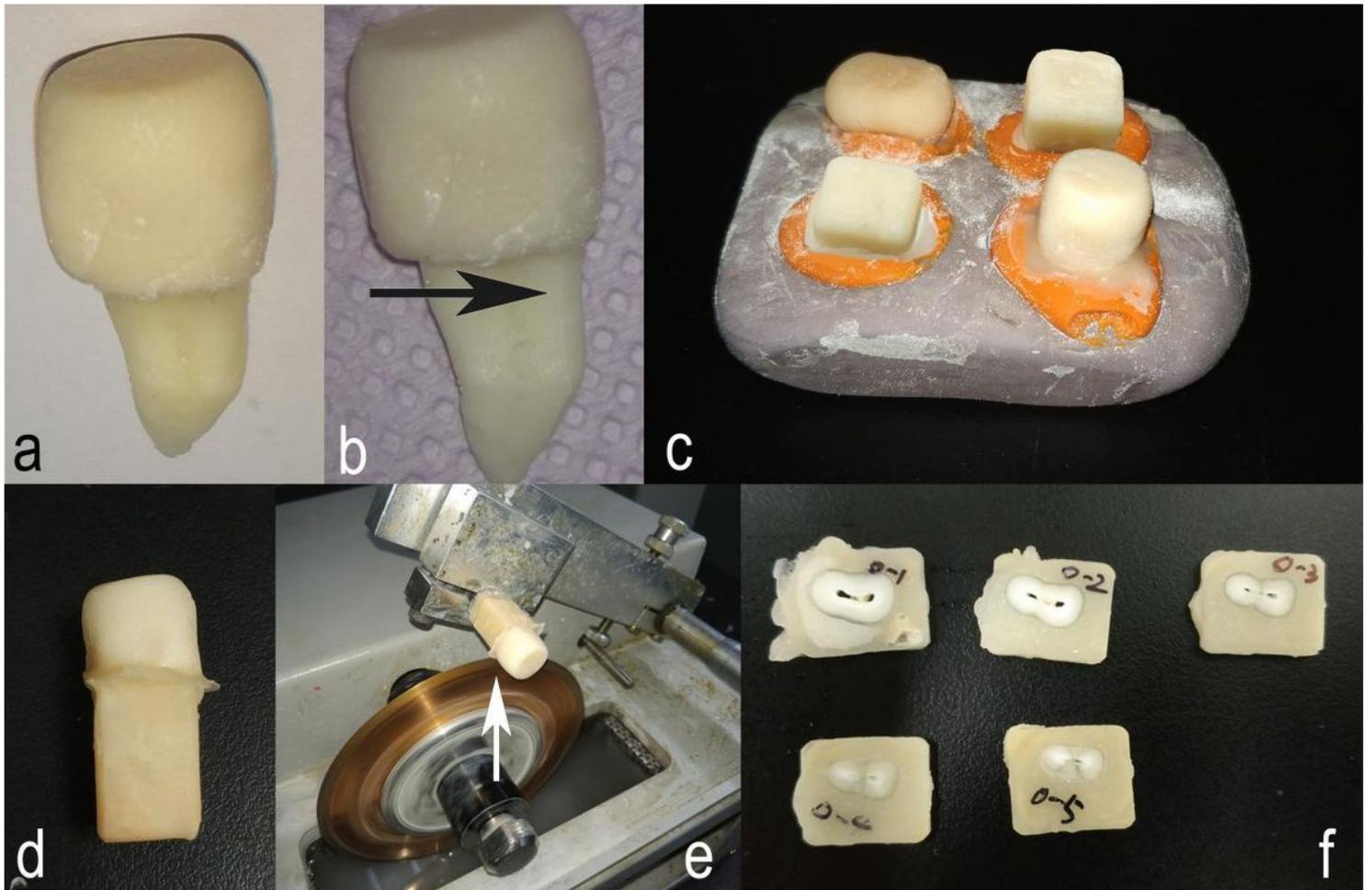


Figure 1

(a) The crown of the teeth was embedded with general purpose acrylic resin. (b) Fracture line was observed on the surface of the root after soaking these teeth in liquid nitrogen and hot water cyclically. (c) The roots of the teeth were embedded with acrylic resin in a square mold. (d) The whole tooth was embedded with acrylic resin. (e) Horizontal root sections were acquired using a slow-speed saw. (f) The root sections with fracture lines were marked and numbered.

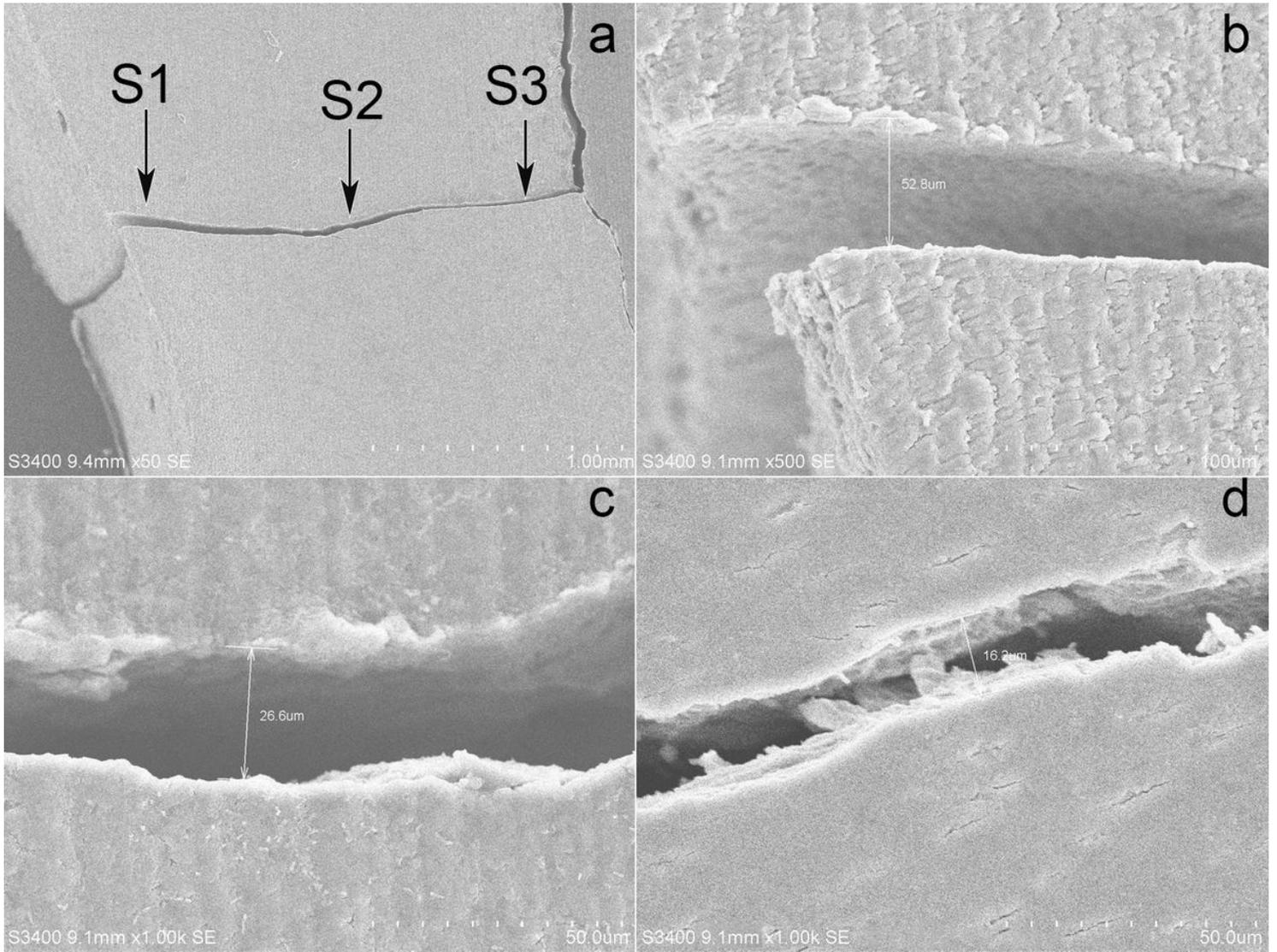


Figure 2

Widths of fracture lines measured at three points (S1, S2, and S3).

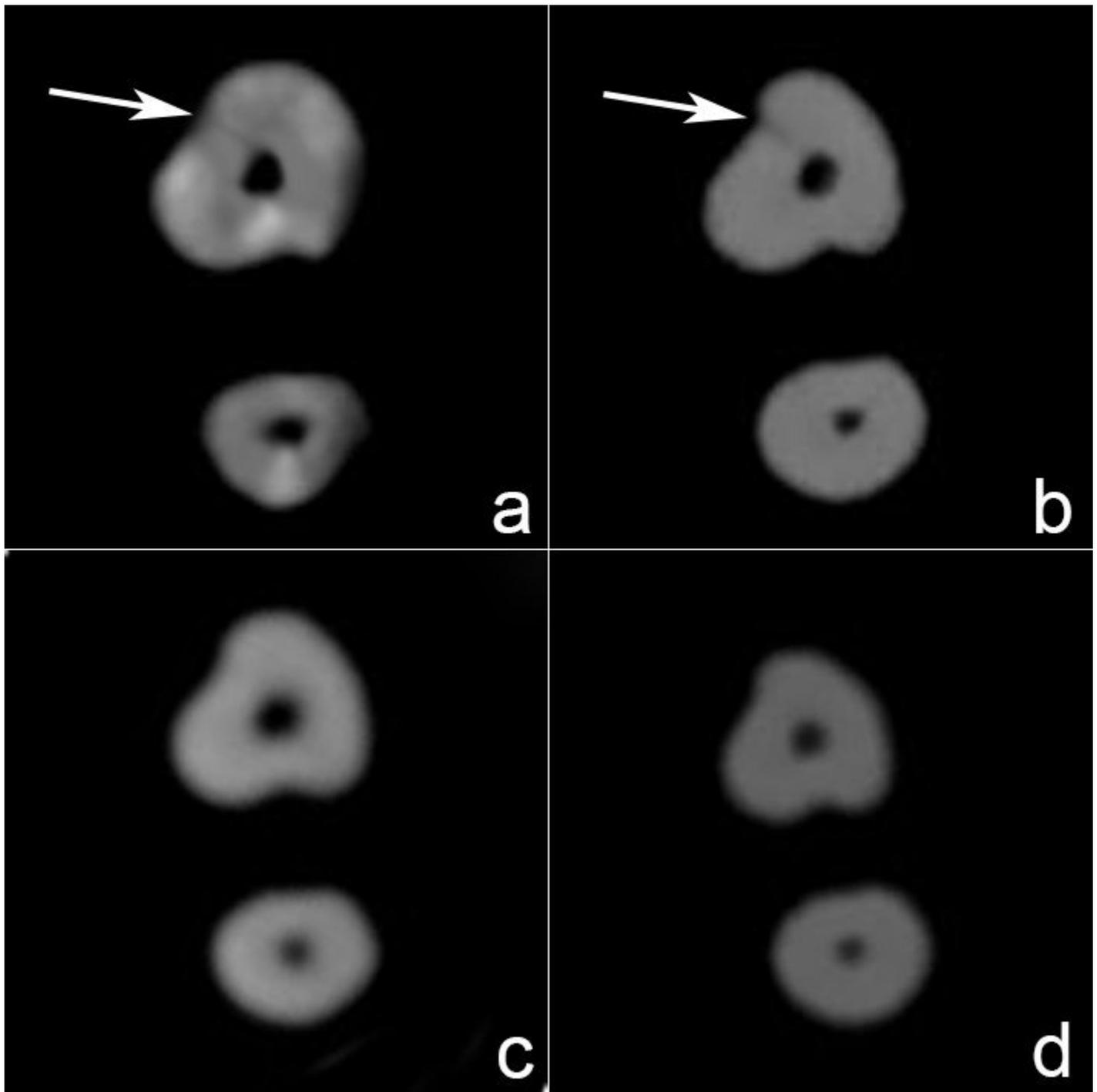


Figure 3

Example CBCT axial images of one tooth with root fracture scanned with the four CBCT units. (a, b) Fracture lines could be found on images scanned with 100 μ m voxel size of Planmeca Promax 3D Max and 100 μ m voxel size of NewTom VGi. (c, d) No fracture lines could be found on images scanned with 100 μ m voxel size of Soredex Scanora3D and 125 μ m voxel size of Kavo 3D eXam.