
Accuracy of intraoral radiography, multidetector helical CT, and limited cone-beam CT for the detection of horizontal tooth root fracture

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Objective. The accuracies of intraoral radiography (IOR), multidetector helical computerized tomography (MDHCT) at slice thicknesses 0.63 mm and 1.25 mm, and limited cone-beam computerized tomography (LCBCT) were compared for detection of horizontal tooth root fracture.

Study design. In 7 beagle dogs, 28 maxillary anterior teeth were used, of which 13 had artificially induced horizontal root fracture. The specimens were examined by the above-mentioned 4 modalities. Diagnosis of root fracture was based on direct visualization of radiolucent line in each image by 6 radiologists.

Results. Sensitivity, negative predictive value, and diagnostic accuracy (true positives + true negatives) for detecting fracture lines in LCBCT (0.96 ± 0.04 , 0.97 ± 0.03 , 0.93 ± 0.04 , respectively) were significantly higher than MDHCT at 0.63 mm (0.76 ± 0.09 , 0.8 ± 0.05 , 0.8 ± 0.05 , respectively), MDHCT at 1.25 mm (0.49 ± 0.09 , 0.66 ± 0.04 , 0.69 ± 0.05 , respectively), and IOR (0.51 ± 0.18 , 0.67 ± 0.08 , 0.69 ± 0.08 , respectively). Specificity and positive predictive value showed no significant intermethod difference among the 4 modalities.

Conclusion. Limited cone-beam CT is more useful than the other 3 radiographic modalities for diagnostic imaging of horizontal tooth root fracture. (*Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009;108:e70-e74)

Diagnosis of tooth root fracture is an important procedure to assess the prognosis and determine the appropriate treatment for the individual tooth. Intraoral radiography (IOR) is the most widely used imaging modality to detect root fracture. However, detection accuracy is low and problematic.^{1,2} Recently, 3-dimensional (3D) images using various computerized tomography (CT) methods have been adopted to overcome the inherent disadvantages of conventional radiographic methods, i.e., magnification, distortion, and anatomic superimposition of 2-dimen-

sional images. Recently, limited cone-beam X-ray CT (LCBCT) has been developed for regional small-field-of-view (SFOV) dentomaxillofacial imaging as an alternative to conventional CT, providing high-resolution images at relatively low radiation dose.³⁻⁶ Regarding vertical root fracture, it has previously been reported that helical CT (HCT) or LCBCT is superior to IOR, because axial CT sections perpendicular to the fracture line are ideal for diagnosis of vertical fractures.^{2,7} On the other hand, assessment of horizontal root fracture using HCT or LCBCT has yet to be reported conclusively. Root fracture caused by trauma more frequently occurs in the horizontal plane than in the vertical plane; moreover, the horizontal fracture line is barely demonstrable on a conventional dental radiograph immediately after trauma.^{1,8,9}

Therefore we wished to investigate the diagnostic accuracy of IOR using bisecting technique, multidetector helical CT (MDHCT) with slice thicknesses of 0.63 mm and 1.25 mm, and LCBCT using dental 3D CT for detection of experimentally induced horizontal root fractures in dog teeth.

MATERIALS AND METHODS

Animals and experimental procedures

Twenty-eight maxillary anterior teeth (bilateral first and second incisors) in seven beagle dogs at 18 months of age were extracted with local anesthesia (2% lidoca-

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Received for publication Apr 27, 2009; returned for revision Jul 3, 2009; accepted for publication Jul 8, 2009.

1079-2104/\$ - see front matter

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doi:10.1016/j.tripleo.2009.07.009

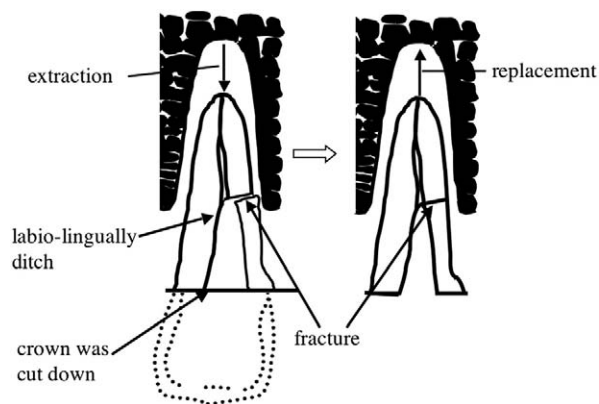


Fig. 1. Illustration of how to induce an experimental root fracture.

nine; Fujisawa Pharmaceutical Co., Tokyo, Japan) under sodium pentobarbital anesthesia (Wako Pure Chemical Industries, Tokyo, Japan) at a dose of 25 mg/kg body weight to eliminate animal's suffering. The crowns of the extracted teeth were reduced to approximately 2 mm above the cement-enamel junction (Fig. 1). All roots were labiolingually grooved from the surface to the middle of the root using a tapered diamond bar (Diamond Point FG 201; Shofu, Kyoto, Japan). Using this guide groove, a root fracture in single horizontal plane was experimentally induced using a flat head screwdriver in 13 randomly selected teeth. The fragments were thoroughly held together and glued in their respective original positions using strong glue (Aron Alpha; Toagosei Co., Tokyo, Japan). All extracted teeth, both with and without induced fractures, were replaced into their original sockets and fixed using dental adhesive (Super Bond C&B; Sunmedical Co., Shiga, Japan). All animals were then euthanized using anesthesia overdose with sodium pentobarbitone by intravenous injection into the saphenous vein. Then the maxillary anterior teeth were excised with surrounding alveolar bone and soft tissues. The specimens were stored in 10% buffered formalin until imaging examinations were performed. The width of the fracture line was measured using a micro-CT device (tube voltage 60 kV, tube current 100 μ A, slice thickness 0.013 mm; MCT-CB100MF; Hitachi Medical Corp., Tokyo, Japan). Prior approval for all research protocols was obtained from the Institute for Experimental Animals at the Tohoku University School of Medicine.

Imaging procedures

Intraoral radiographs were obtained using standardized X-ray exposure (DFW-20; Asahi Roentgen Co., Kyoto, Japan) operated at 65 kV, 20 mA, and 0.1-

second exposure time with a focus-film distance of 40 cm. Conventional dental film (Insight Dental Film IP-21; Eastman Kodak Co., Rochester, New York) was used as the image detector and images obtained using a bisecting technique at an angle of +55 degrees to the occlusal plane.

Multidetector helical CT (MDHCT) was performed using a Somatom Emotion 6 (Siemens, Erlangen, Germany) operated at 130 kV and 80 mAs. The specimens were stabilized on the gantry, and axial scan images parallel to the occlusal plane were taken at 2 slice thickness settings: 0.63 mm using detector collimation 0.5 mm, and slice thickness of 1.25 mm using detector collimation of 1.0 mm. Each image was reconstructed to a 0.2-mm-interval image.

Limited cone beam CT (LCBCT) was performed using an SFOV unit (PSR 9000N; Asahi Roentgen Co.) and operated at a standardized exposure of 60 kV, 4 mA, and 13.3 seconds, with a slice thickness of 0.1 mm. Specimens were positioned so that the occlusal plane was parallel with the floor. Volumetric imaging produced a limited cylindrical field of view (FOV; 40 mm height, 41 mm diameter). All radiographic images were taken by an experienced radiologic technologist.

Visual evaluation

Six oral and maxillofacial radiologists who were blinded as to procedure, methods, and the condition of the roots of the teeth observed the images independently. Intraoral radiographs were observed on a light-box. Volumetric data obtained using MDHCT and LCBCT were exported as DICOM and imported into a specially designed DICOM viewer software program (ExaVision Lite; Ziosoft, Tokyo, Japan). Data were reconstructed to provide cross-sectional coronal images perpendicular to the fracture lines. Observers were free to use the available image-enhancement options (density, contrast, gamma curve, and magnification) on a 19-inch flat-panel monitor. Both intraoral radiographs and reconstructed coronal images were coded and presented to the observers in a random order. A fracture was diagnosed as a direct visualization of a radiolucent line traversing the root. Evaluation of the presence of a fracture line was dichotomous: yes/no.

Data analysis

To examine interobserver agreement for each of the four modalities, the 6 observers were linked into pairs (total 15 pairs). The agreement of each pair was calculated. Finally, the interobserver agreement was expressed as the mean \pm SD of the 15 pairs. The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and diagnostic accuracy (true positives + true negatives) of recognizing the

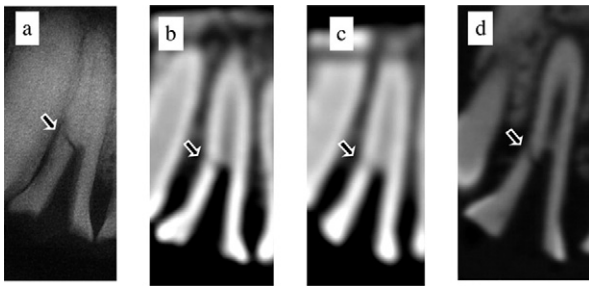


Fig. 2. Radiographies of the right maxillary second incisor. Intraoral radiography (a), multidetector helical computerized tomography (MDHCT) (0.63 mm) (b), MDHCT (1.25 mm) (c), and limited cone-beam computerized tomography (LCBCT) (d) show a fracture line (arrows) at the distal side of the tooth.

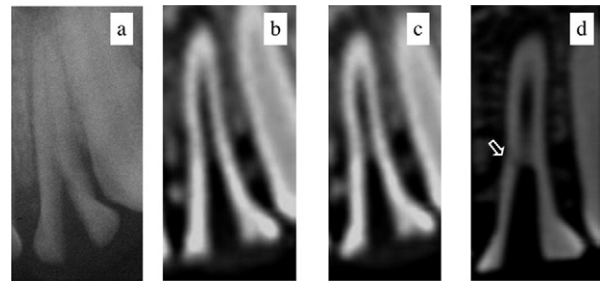


Fig. 4. Radiographies of the left maxillary second incisor. LCBCT (d) shows a fracture line (arrow) at the medial side of the tooth, but intraoral radiography (a), MDHCT (0.63 mm) (b), and MDHCT (1.25 mm) (c) barely show a fracture line. Abbreviations as in Fig. 1.

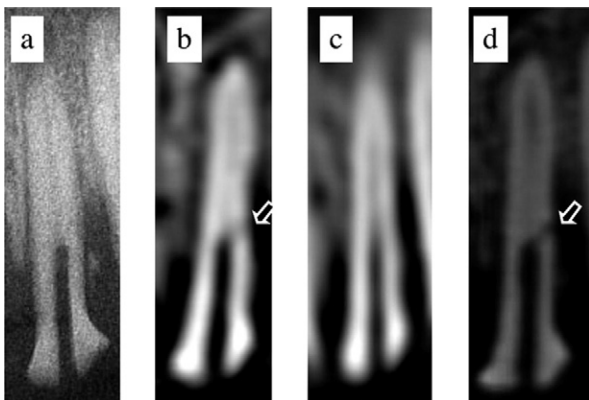


Fig. 3. Radiographies of the left maxillary first incisor. MDHCT (0.63 mm) (b) and LCBCT (d) show a fracture line (arrows) at the distal side of the tooth, but intraoral radiography (a) and MDHCT (1.25 mm) (c) barely show a fracture line. Abbreviations as in Fig. 1.

presence of a fracture line were determined for each radiographic modality. All numeric data were calculated as the mean \pm SD of 6 observers. Statistical analyses were carried out using Stat View software (version 5; SAS Institute Japan, Tokyo, Japan). The statistical significance of differences was determined using Scheffé's F test after analysis of variance using the Kruskal-Wallis test. Differences were considered to be significant for $P < .05$.

RESULTS

Figures 2, 3, and 4 show representative images of specimens with experimentally induced fracture teeth. In Fig. 2, a radiolucent line was found on all images obtained using the 4 radiographic modalities. In Fig. 3, the radiolucent line was found in MDHCT (slice thickness: 0.63 mm) and LCBCT. Nevertheless, it was difficult to observe the line in the intraoral radiograph and

MDHCT (slice thickness 1.25 mm). As demonstrated in Fig. 4, the radiolucent line was found only in LCBCT.

Figure 5 shows mean interobserver agreement for the 4 radiographic modalities. LCBCT showed a significantly greater value than the other 3 modalities. No significant difference was found among intraoral radiography, MDHCT (slice thickness: 0.63 mm) and MDHCT (slice thickness 1.25 mm).

Figure 6 shows the sensitivity, specificity, PPV, NPV, and diagnostic accuracy (true positives + true negatives) for the detection of the fracture line for each modality. Sensitivity, NPV, and diagnostic accuracy for detecting fracture lines in LCBCT (0.96 ± 0.04 , 0.97 ± 0.03 , 0.93 ± 0.04 , respectively) were significantly higher than MDHCT at 0.63 mm (0.76 ± 0.09 , 0.8 ± 0.05 , 0.8 ± 0.05 , respectively), MDHCT at 1.25 mm (0.49 ± 0.09 , 0.66 ± 0.04 , 0.69 ± 0.05 , respectively), and intraoral radiography (0.51 ± 0.18 , 0.67 ± 0.08 , 0.69 ± 0.08 , respectively). Specificity and PPV showed no significant intermethod difference among the 4 modalities. No significant difference was noted between MDHCT (slice thickness 1.25 mm) and intraoral radiography.

The mean width of the fracture line measured using micro-CT was 0.243 ± 0.069 mm.

DISCUSSION

Single horizontal root fracture in the middle or apical third of a tooth root is the usual finding after acute trauma of a tooth.¹⁰ To detect the fracture line, intraoral radiography (IOR) has been used widely, because of its low cost, convenience, and high resolution. When interpreting the diagnostic image, a radiolucent line between the fragments and a discontinuity of periodontal ligament shadow are important signs for diagnosis of the root fracture.¹⁰ However, subtle fissures in the early stages without separation of the adjacent segments are

	Intraoral radiography	MDHCT(0.63mm)	MDHCT(1.25mm)	LCBCT
Inter-observer agreement	0.719 ± 0.201	0.774 ± 0.091	0.783 ± 0.102	0.933 ± 0.029

Fig. 5. Interobserver agreement for the 4 radiographic modalities (mean ± SD). **P* < 0.05; ***P* < 0.01; ****P* < 0.001.

	Intraoral radiography	MDHCT(0.63mm)	MDHCT(1.25mm)	LCBCT
Sensitivity	0.512 ± 0.179	0.756 ± 0.089	0.492 ± 0.088	0.961 ± 0.042
Specificity	0.844 ± 0.217 N. S.	0.822 ± 0.091	0.853 ± 0.086	0.911 ± 0.068
PPV	0.837 ± 0.214 N. S.	0.805 ± 0.072	0.762 ± 0.135	0.907 ± 0.067
NPV	0.674 ± 0.081	0.802 ± 0.049	0.661 ± 0.036	0.965 ± 0.037
Diagnostic accuracy	0.69 ± 0.077	0.797 ± 0.049	0.685 ± 0.047	0.934 ± 0.041

Fig. 6. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and diagnostic accuracy (true positives + true negatives) for the 4 radiographic modalities (mean ± SD). **P* < 0.05; ***P* < 0.01; ****P* < 0.001. N.S., Not significant.

sometimes not detectable using IOR before a soft-tissue proliferation separates the root segments.^{7,11} To simulate the clinical situation, each experimental tooth used in the present study was exactly fractured in a single horizontal plane in the middle of the tooth root by the guide groove. Then the fragments were tightly glued together in their original position. Regarding the modality used in this experiment, the MDHCT image was reconstructed to the 0.2-mm-interval image, because reconstructing 1-2 sections per collimation interval has been recommended for routine diagnosis by virtue of its high longitudinal resolution¹² and because the reconstructed interval was less than the width of artificially produced fracture line (0.243 ± 0.069 mm) in this experiment.

This study showed that the sensitivity of LCBCT was highest, followed by that of MDHCT (slice thickness 0.63 mm), for detection of horizontal tooth root fracture. The difference in sensitivity among the modalities might depend on the difference of spatial resolution ability of these modalities. Especially, slice thickness,

which affected the spatial resolution of the reconstructed coronal images, differed among the 3 CT modalities (LCBCT 0.1 mm, MDHCT 0.63 mm and 1.25 mm). Regarding the spatial resolution capabilities, isotropic resolution has been reported as 2 line pairs per millimeter (lp/mm) on the z-axis when the MDHCT system with a detector configuration of 32 × 0.6 mm was used, corresponding to an object size of 0.25 mm that can be resolved,¹³ whereas the resolution of LCBCT is estimated as 3.1 lp/mm.¹⁴ On the other hand, dental film used for the IOR has higher resolution than these CT images, because it can resolve >22 lp/mm,¹⁵ which is far less than the width of the experimentally induced fracture line. Indeed, when the X-ray beam was projected parallel to the fracture line, IOR revealed a clear line, as shown in Fig. 2. However, the X-ray beam in bisecting technique is generally exposed downward angularly to the long axes of maxillary incisors because the vertical angle of the X-ray beam is determined by the angle formed between the film and the long axis of

the tooth, resulting in less imaging of the horizontal root fracture (Fig. 3). The sensitivity of IOR, as a result, was inferior to that of LCBCT and MDHCT (slice thickness 0.63 mm), for which the cross-sectional images to the fracture line can be observed.

Youssefzadeh et al.⁷ compared the sensitivity of IOR and HCT for the detection of vertical root fracture and found that HCT axial sections obtained with a slice thickness of 1.5 mm were superior. In the present study of horizontal fractures, sensitivity in MDHCT with a section thickness of 1.25 mm was similar to that of IOR, and MDHCT at 0.63 mm was superior, suggesting that the slice thickness in CT scan should be less for detection of horizontal root fracture than that for detection of vertical fracture.

The diagnostic accuracy of LCBCT was significantly higher among the 4 radiographic modalities; the second was MDHCT (slice thickness 0.63 mm), and MDHCT (slice thickness 1.25 mm) was similar to IOR. Such differences in accuracy might not depend on the differences in true negatives, but rather on true positives, considering that specificity and PPV in the 4 modalities showed no significant difference. In addition, we previously described that the integral absorbed dose of radiation using LCBCT was approximately 1/15 that using HCT when the exposure condition of the latter was optimized.^{4,16}

CONCLUSION

Limited cone-beam CT has the highest sensitivity and diagnostic accuracy for detecting horizontal root fracture among the 4 radiographic modalities examined. LCBCT should be considered as the most reliable imaging modality of choice for the diagnosis of horizontal root fracture.

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