RESEARCH

Assessment of vertical root fractures using three imaging modalities: cone beam CT, intraoral digital radiography and film

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Objectives: The aim of this study was to assess the accuracy of cone beam CT (CBCT) in detecting vertical root fractures and to compare the accuracy with images from an intraoral sensor and from conventional intraoral film.

Methods: 60 extracted, single-rooted human teeth were divided equally into two groups: a control group of 30 teeth and an induced fracture group of 30 teeth. All teeth were randomly placed into sockets in six dry mandibles. Each tooth was imaged by three modalities: CBCT, intraoral digital radiography and intraoral F-speed film. Three beam angulations (an orthogonal projection and additional projections with $\pm 20^\circ$ horizontal shifts of the central ray) were used when radiographs were made using film and a digital sensor. Three oral and maxillofacial radiologists evaluated the presence of root fractures twice in each image modality using a five-point confidence rating scale. Areas under receiver operating characteristic curves (A_z) were computed for each observer and modality and were tested for statistical differences using the Kruskal–Wallis test.

Results: There was no statistical difference in the performance of the three modalities (mean of A_z values: CBCT = 0.811, film = 0.797 and sensor = 0.775; $p = 0.771$).

Conclusions: There was no significant difference between intraoral film, a high-resolution complementary metal oxide semiconductor digital imaging system and CBCT in detecting vertical root fractures in mandibular single-rooted teeth.

Dentomaxillofacial Radiology (2012) **41**, 91–95. doi: 10.1259/dmfr/49798768

Keywords: cone beam computed tomography; vertical root fracture

Introduction

Vertical root fractures are an expected danger to the life of a tooth and are one reason for tooth extraction. They occur most often in endodontically treated maxillary first and second premolar teeth¹ and in non-endodontically treated molar teeth.²

The diagnosis of vertical root fractures is very difficult and is still problematic for many dentists compared with the diagnosis of other fractures, such as crown fractures, for which many examination procedures are available, *e.g.* light transillumination, the biting test and the blue dye stain test. In general, radiographic examination is the most commonly used method to aid

in detecting vertical root fractures.³ The fracture lines can only be seen if the X-ray beam passes parallel to the fracture direction. Therefore, additional films exposed with the beam approaching from at least two different angles spaced 15° to 20° apart are recommended to increase the likelihood of revealing the fractures.^{4–6} Although additional films may be made at different angles, detection of vertical root fractures is a challenge for dentists because many vertical fractures present with no radiographic signs.⁷

Over the last 20 years, intraoral digital imaging systems have been developed to replace film as an image-recording medium.⁸ The digital imaging systems provide many advantages when compared with conventional films, *e.g.* dose reduction for patients, tools or programmes for image enhancement and the elimination of darkrooms and chemical solutions. Many

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Received 1 June 2009; revised 1 November 2010; accepted 10 November 2010

studies on root fracture detection have been published, using both conventional films and digital imaging systems.^{3,6,9}

Unfortunately, both conventional films and digital imaging systems provide poor sensitivity in the detection of vertical root fractures. This limitation is the result of a combination of factors: superimposition of overlying and adjacent anatomical structures, processing errors from manual film processing or from automatic film processing machines, a beam direction that may not be parallel to the fracture line and the display of a two-dimensional (2D) image of a three-dimensional (3D) object.^{5,10,11} These limiting factors indicate the need for the development and study of alternative diagnostic imaging systems that carry the potential for improving detection.¹²

In recent years, cone beam CT (CBCT), also called digital volume tomography,^{10,13} has been introduced as an alternative to film-based radiography and conventional digital radiographic systems. This modality is able to present images in three planes (sagittal, coronal and axial) and also produces 3D imaging of the hard tissues of the jaws with reduced radiation dose.¹⁴ The feasibility of this imaging technology has been reported for measurement of caries lesion depth,¹⁵ evaluation of bone grafts in patients with a cleft palate,¹⁶ localization of impacted teeth,¹⁷ evaluation of root resorption,¹⁸ examination of accessory canals, location, shape and length of roots, etc.¹⁹ However, few studies have reported the utility of CBCT for root fracture detection.^{20–22} Therefore, the purposes of this study were to investigate the accuracy of CBCT in detecting vertical root fractures and to compare this modality with a complementary metal oxide semiconductor (CMOS)-based digital radiographic system and with conventional film.

Materials and methods

60 extracted single-rooted human anterior or premolar teeth were used. For all teeth, endodontic access openings were made and endodontic instruments with files 15 to 45 were used to prepare the root canals in order to fit the universal testing machine instrument used to make fracture lines. Vertical root fractures were created in 30 teeth as follows. Each root was coated with a layer of wax and placed in a separate acrylic block. A tapered wedge was placed in the canal with controlled pressure applied by a universal testing machine, which was set to stop when the root fractured. Each fractured tooth was removed from the acrylic block. The pattern of the fracture line was confirmed using 1% methylene blue solution. This solution was placed in the canal and allowed to flow through the fracture. The remaining 30 teeth served as controls and the absence of fractures in these teeth was also confirmed.

The teeth were divided randomly into six groups and placed in dry edentulous mandibles (a set of five teeth

was placed in the sockets of the canine, the first premolar, the second premolar and the mesial and distal roots of the first molar on both sides of each mandible and were held with boxing wax). The dry mandible was placed behind a 10 mm thick block of soft tissue-equivalent material before radiographs were made.

All 60 teeth were radiographed with 3 different imaging systems: CBCT (Veraviewepocs 3D, J. Morita Mfg. Corp., Kyoto, Japan), CMOS-based intraoral digital imaging (Digital Kodak RVG 5000, Eastman Kodak Company, Rochester, NY) and size 2 F-speed intraoral films (Kodak Insight Dental Film, Eastman Kodak Company). For CBCT, the images were acquired at 70 kVp, 3 mA and 9.4 s with a slice thickness of 1.5 mm and a slice interval of 1.0 mm. All images were saved on a computer (Dell Precision 490, Dell Computer Corporation, Round Rock, TX) and written onto compact disks using the ODViewer program (One Data Viewer, J. Morita Mfg. Corp.). For digital and conventional intraoral radiography, each tooth was imaged with a Planmeca Intra machine (Planmeca Oy, Helsinki, Finland) using the paralleling technique with three angulations of X-ray beam: orthogonal, 20° mesial and 20° distal to the long axis of the teeth. The exposure factors were 70 kVp, 8 mA and 0.160 s for conventional intraoral radiography and 66 kVp, 8 mA and 0.125 s for intraoral digital radiography. The source-to-object and the object-to-receptor distances were fixed at 35 cm and 2 cm, respectively.

Films were processed automatically using a Clarimat 300® machine (Gendex, London, UK) according to the manufacturer's instructions and were mounted in frames. The intraoral digital images were saved in a computer (HP Pavilion dv9500 Notebook PC, Hewlett-Packard, Palo Alto, CA).

Each of three observers had more than 5 years' experience as radiologists and they evaluated all the images from the three modalities separately to detect the presence of vertical root fractures; they could not begin with another modality until all images from the previous modality were evaluated. The reading order of modalities for interpretation was film, intraoral digital radiography and CBCT. For conventional intraoral radiography, three projected films of each tooth were shown at the same time on a light box. The observers used a magnifying glass to view the films. For intraoral digital radiography, three projected images of each tooth were displayed together on the same computer. The observers were asked to identify the presence or absence of the fracture in each film. The observers were allowed to adjust the visual characteristics, contrast and density of the images. For CBCT, the images were presented in three planes (sagittal, coronal and axial) on a computer with an effective resolution of 1440 × 900 pixels (17 inch monitor HP Pavilion dv9500 Notebook PC, Hewlett-Packard). The observers were permitted to click on a location of interest in any one of the planes. In each projection the observers

were asked to identify the presence or absence of a fracture.

Each modality was evaluated twice at an interval of at least 2 weeks. The viewing time to evaluate the presence or absence of vertical root fractures was unrestricted. The observers recorded their observations on a five-point confidence scale as follows:

- 1 = fracture definitely not present;
- 2 = fracture probably not present;
- 3 = unsure;
- 4 = fracture probably present; and
- 5 = fracture definitely present.

Cohen's kappa statistic²³ was calculated for the degree of agreement in detecting root fractures in each imaging system (intra- and interobserver agreement). Receiver operating characteristic (ROC) analyses were performed, followed by the Kruskal–Wallis test to assess for the effects of observer and imaging modality.

Results

The pattern of root fractures, the number of roots and the proportion of true positive interpretations from three observers (two observations each) are shown in Table 1.

The areas under the ROC curve (A_z) values from the ROC analysis of the film and sensor for the accuracy of interpretations between using only orthogonal angulation and the three different angulations (orthogonal, 20° mesial and 20° distal to the long axis of the teeth) of the X-ray beam are shown in Table 2. The A_z values from the ROC analysis of the three imaging modalities for each observer and the means of the A_z values of each imaging modality are presented in Table 3.

Two out of the three observers performed best with CBCT. The mean A_z value of observations for CBCT was slightly higher than for the other modalities. However, the Kruskal–Wallis test revealed no statistically significant differences between the three imaging

modalities ($p = 0.771$). The Kruskal–Wallis test showed no significant differences within each observer for an interpretation of vertical root fracture in any modality.

The kappa values for intraobserver agreement ranged for all modalities from 0.671 to 0.931 for two observers, which is considered as substantial to almost perfect agreement, while the intraobserver agreement of the other observer was fair (0.304–0.388).

For the interobserver agreement, the kappa value for film was 0.622 (range 0.241–0.895), for the CMOS sensor it was 0.539 (range 0.223–0.738) and for CBCT it was 0.502 (range 0.357–0.664).

Discussion

This study investigated the accuracy of CBCT in detecting vertical root fractures and compared CBCT images with CMOS-based digital images and with conventional film images. The results of this study show that CBCT can be used to improve the accuracy of identifying vertical tooth fractures. However, no significant differences were found among the three modalities: conventional film, intraoral digital sensor and CBCT. There may be many possible explanations for the lack of significant differences between the 3D CBCT and the 2D digital and conventional systems.

First, the direction of the fracture lines may have affected the results. In this study, almost all of the fracture lines that could be detected by intraoral digital and conventional radiographs were bucco-lingual in direction. There were only three roots in our study in which the fracture lines presented in a mesio-distal direction. All of the observers correctly detected the mesio-distal fractures on the CBCT images (Table 1). If the number of roots with mesio-distal fracture lines were higher, the accuracy of CBCT images might have been significantly better than that of film and digital images for vertical root fracture detection.

Second, both intraoral digital and conventional radiographs were taken at three different beam angulations, rather than the clinically normal single

Table 1 Pattern and number of root fractures and proportion of true positive interpretations for three imaging modalities: film, sensor and cone beam CT (CBCT)

Direction of fracture lines	Number of roots	Proportion of true positive interpretations		
		Film	Sensor	CBCT
Bucco-lingual direction	20	88/120	106/120	117/120
Oblique direction	7	21/42	26/42	27/42
Mesio-distal direction	3	9/18	6/18	18/18
Total	30			

Table 2 Area under the receiver operating characteristic curve (A_z) values of film and sensor for accuracy of interpretations between using orthogonal angulation and three different angulations

Imaging modalities	(A_z)	
	Orthogonal angulation	Three different angulations
Film	0.683	0.797
Sensor	0.750	0.775

projection. The results reveal that interpretation using three different beam angulations was better than using only one beam angulation (Table 2). This finding echoes that of Wenzel and Kirkevang.³

Third, the absence of fillings and post-restorations was intended to reduce factors that might affect the interpretation, such as superimposition of the filling materials over the fracture lines in both intraoral digital and film images and the obstruction of fracture lines by metal artefacts in CBCT. We used single-rooted teeth to eliminate the effects of factors such as overlapping of roots in multirooted teeth. If multirooted teeth were used, CBCT might have given significantly higher scores than digital and conventional radiographs because of the multiplanar views of the roots.

Fourth, this study used dry edentulous mandibles, which, compared with the maxilla, have fewer anatomical structures that may be superimposed over the roots and inhibit vertical root fracture detection for all three modalities. This may have resulted in easy interpretation of the fracture lines in the 2D modalities. If dry maxillae were used instead of mandibles, CBCT might have provided significantly improved performance compared with digital and conventional radiography because more information can be seen in the three different image planes of CBCT.

Fifth, the half-circle scan arc of the Veraviewepocs 3D²⁴ reduces scanning time but it produces a high-noise image. Other CBCT machines have been developed with different degrees of rotation whose tube heads rotate 360°. ^{25–27} Such machines might have given different results. It would be interesting to test this hypothesis using different machines with the same study model.

Sixth, the slice thickness of CBCT images in this study was set at 1.5 mm. The slice thickness selected may have had some influence on the results of this study. A finer slice thickness might have shown higher accuracy than we found in this study. The effects of image resolution should be studied in the future.

Seventh, the images were viewed in the same order by all observers. The reading order may have affected the evaluation. However, there were no significant differences between the three modalities in the detection of

Table 3 Area under the receiver operating characteristic curve (A_z) values of three imaging modalities; film, sensor and cone beam CT (CBCT)

Observer	Imaging modalities					
	Film		Sensor		CBCT	
	A_z	SD	A_z	SD	A_z	SD
Observer 1	0.834	0.055	0.834	0.056	0.875	0.049
Observer 2	0.825	0.057	0.792	0.061	0.817	0.058
Observer 3	0.734	0.065	0.700	0.067	0.742	0.066
Mean	0.797	0.059	0.775	0.062	0.811	0.067

SD, standard deviation.

vertical root fractures. This may suggest that reading order bias was not significant.

In clinical situations, thorough clinical and radiographic examinations are important for the detection of vertical root fractures. Radiographic examinations may begin by using intraoral digital or film imaging with more than one beam angulation, especially when there is no CBCT available. If the diagnosis is still questionable, then CBCT should be prescribed in order to increase the likelihood of detecting the fractures.

Conclusions

There was no significant difference between intraoral film, a high-resolution CMOS digital imaging system and CBCT in detecting vertical root fractures in mandibular single-rooted teeth. However, CBCT showed the highest score in detecting vertical root fractures.

Acknowledgments

The authors would like to thank the Oral Radiology Clinic, Faculty of Dentistry, Chiang Mai University, for the use of its equipment for the research project, the Research Centre of the Faculty of Dentistry, Chiang Mai University, for the use of the universal testing machine and the Grace Dental Care Clinic, Chiang Mai, for the use of the CBCT machine. The authors also thank Professor M Kevin O Carroll, Professor Emeritus, University of Mississippi School of Dentistry, USA, and faculty consultant, Chiang Mai University Faculty of Dentistry, for his assistance in editing the manuscript, Dr Phattaranant Mahasantiapiya for being one of the observers, and Dr Nopawong Luevitoonvechakij and Dr Thepparat Khemalelakul for their assistance in using the universal testing machine.

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