ASSessment of vertical root fractures using three imaging modalities: cone beam computed tomography, intraoral digital radiography and film

ABSTRACT

The objectives of this study were to assess the accuracy of cone beam computed tomography in detecting vertical root fractures and to compare the accuracy with that of images from an intraoral sensor and with that of conventional intraoral film. Sixty extracted single-rooted human teeth were divided equally into two groups; control and induced fracture groups. Three dental radiologists interpreted each image modality twice by using a five point confidence-rating scale. Receiver Operating Characteristic curves and the Kruskal-Wallis were used for statistical analysis. The result showed that cone beam computed tomography had highest score in detecting vertical root fractures. However, there was statistically no significant difference between the three imaging modalities for vertical root fracture detection (p>0.05).

Key Words : Cone Beam Computed Tomography, Vertical root fracture

* Master degree of Science (Dentistry) dental student, Track of Oral Diagnostic Sciences (Oral and Maxillofacial Radiology), Chiang Mai University, Chiang Mai, Thailand

** Dr., Department of Dental Radiology, Faculty of Dentistry, Chiang Mai University, Chiang Mai, Thailand

*** Assist. Prof., Department of Dental Radiology, Faculty of Dentistry, Chiang Mai University, Chiang Mai, Thailand

**** Assoc. Prof., Department of Odontology and Oral pathology, Faculty of Dentistry, Chiang Mai University Chiang Mai, Thailand
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 teeth (Morfis, 1990) and in non-endodontically treated molar teeth (Chan et al., 1999).

The diagnosis of vertical root fractures is very difficult and still problematic for many dentists when 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 vertical root fracture detection (Wenzel and Kirkevang, 2005). The fracture lines can be seen only 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, 15 to 20 degrees apart, are recommended to increase the likelihood of revealing the fractures (Andreasen 1989; Kositbowornchai et al., 2003; Mora et al., 2007). Although additional films may be made at different angles, detection of vertical root fractures is a challenge for dentists because many vertical fractures have no radiographic signs (Tamse et al., 1999).

Over the last 20 years, digital imaging systems, consisting of charge-coupled devices (CCD), or complementary metal oxide semiconductor (CMOS) sensors, or photostimulable storage phosphor (PSP) plates, have been developed to replace film as an image-recording medium (Mouyen et al., 1989). The digital imaging systems provide many advantages when compared to conventional films, e.g., dose reduction for patients, tools or programmes for image enhancement, and the elimination of darkrooms and chemical solutions. Many studies on root fracture detection have been published, using both conventional films and digital imaging systems (Kositbowornchai et al., 2001; Kositbowornchai et al., 2003; Wenzel and Kirkevang, 2005). These studies compared the diagnostic potential of direct digital radiography with that of conventional film for detecting experimental root fractures, compared the diagnostic accuracy of a high resolution CCD sensor and a medium resolution PSP plate for detecting experimentally-induced root fractures between images taken with various horizontal and vertical angles, and used digital image enhancement tools, e.g., zoom function, to detect root fractures (Kositbowornchai et al., 2003).

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 image of a three-dimensional (3-D) object (Nair et al., 2001; Cohenca et al., 2007; Mora et al., 2007). These limiting factors indicate the need for the development and study of alternative diagnostic imaging systems that carry the potential for improving detection (Mora et al., 2007).

In recent years, cone beam computed tomography (CBCT), also called digital volume tomography (Nair et al., 2001; Nair et al., 2003) 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 three-dimensional imaging of the hard tissues of the jaws with reduced radiation dose (Patel et al., 2007). The feasibility of this imaging technology has been reported for dental caries detection (Akdeniz et al., 2006), evaluation of bone grafts in patients with cleft palate (Hamada et al., 2005), localization of impacted teeth (Liu et al., 2008), evaluation of root resorption (Kau et al., 2005), examination of accessory canals, location, shape and length of roots, etc (Nair and Nair, 2007). However, the utility of CBCT for vertical root fracture detection has not been reported. 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 CMOS-based digital radiographic system and with conventional film.

Materials and methods

Sixty extracted, single-rooted, human, anterior or premolar teeth were used in the study. For all teeth, endodontic access openings were made and endodontic instruments with files numbered 15 to 45 were used to prepare the root canals. Vertical root fractures were created in 30 of these teeth. Each root was coated with a layer of wax and placed in a separate acrylic block. A tapered-type 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 in the sockets of canine, first premolar, second premolar, mesial and distal roots of first molar on both sides of each mandible and 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 three different imaging systems: CBCT (Veraviewepocs 3D, J. Morita Mfg. Corp., Kyoto, Japan), CMOS-based intraoral digital imaging (Digital Kodak RVG 5000, Eastman Kodak, Rochester, NY) and size 2, F-speed intraoral films (Kodak Insight Dental Film, Eastman Kodak Company Rochester, NY). For CBCT, the images were acquired at 70 kVp, 3 mA and 9.4s with a slice thickness of 1.5 mm and a slice interval of 1.0 mm. All images were saved in the computer and written on CDs using the ODViewer program (One Data Viewer, J. Morita Mfg. Corp.). For intraoral digital radiography and conventional intraoral radiography, each tooth was imaged with a Planmeca Intra machine (Planmeca OY 00880 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 0.160s for conventional intraoral radiography and 66 kVp, 8 mA and 0.125s for intraoral digital radiography. The source-to-object distance and the object-to-receptor distances were fixed at 35 cm. and 2 cm, respectively.

897
Films were processed automatically using a Clarimat 300® machine (Gendex, London, England) 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, CA, USA).

Three radiologists who had over five years’ experience served as observers for the study. Each observer evaluated all the images from the three modalities separately to detect the presence of vertical root fractures, and could not begin with another modality until all images from the previous modality were evaluated. For CBCT, the images were presented in three planes, sagittal, coronal and axial on a computer with an effective resolution of 1,440 x 900 pixels (17-in. monitor HP Pavilion dv9500 Notebook PC). The observers were permitted to click on a location of interest in any one of the planes. For intraoral digital radiography, three projected images of each tooth were displayed on the same computer. The observers were allowed to adjust the visual characteristics, contrast and density of the images. For conventional intraoral radiography, three projected films of each tooth were shown on a light box. The observers used a magnifying glass to view the films.

Each modality was evaluated twice, at least two weeks apart. 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 statistic was calculated for the degree of agreement in detecting root fractures in each imaging system (intra- and inter-observer agreement). Receiver operating characteristic (ROC) analyses were performed, followed by the Kruskal-Wallis test to assess the effects of observer and imaging modality.

**Results**

The $A_z$ values from the ROC analysis of the three imaging modalities for each observer are shown in Table I. The means of $A_z$ values of each imaging modality are presented in Table II.

<table>
<thead>
<tr>
<th>Observer</th>
<th>Imaging modalities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Film</td>
</tr>
<tr>
<td></td>
<td>Area ($A_z$)</td>
</tr>
<tr>
<td>Observer 1</td>
<td>0.834</td>
</tr>
<tr>
<td>Observer 2</td>
<td>0.825</td>
</tr>
<tr>
<td>Observer 3</td>
<td>0.734</td>
</tr>
</tbody>
</table>

*SD: standard deviation.

<table>
<thead>
<tr>
<th>Imaging modalities</th>
<th>Area ($A_z$)</th>
<th>SD*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Film</td>
<td>0.797</td>
<td>0.059</td>
</tr>
</tbody>
</table>
Two out of 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 difference between the three imaging modalities ($p>0.05$). The Kruskal-Wallis test showed no significant difference within each observer for an interpretation of vertical root fracture in any modality.

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

For the inter-observer agreement, the Kappa value for film was 0.622 (range: 0.241-0.895), for the CMOS sensor 0.539 (range: 0.223-0.738) and for CBCT 0.502 (range: 0.357-0.664).

**Discussion**

Detecting vertical root fractures is problematic for many dentists. To our knowledge, there is no published study that uses CBCT in the detection vertical root fractures. The present study aims to assess the accuracy of cone beam computed tomography (CBCT) in detecting of vertical root fractures and to compare it with that of a CMOS sensor in intraoral digital radiography and with that of conventional intraoral film. CBCT is an alternative modality that has become more accepted in dentistry in the last few years and holds promising benefits for the future.

The results from this study showed 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 films, intraoral digital sensor and CBCT. The familiarity of the observers with the interpretation of CBCT images was not the same. It appeared that the more training in the interpretation of CBCT images the better was the interpretation. The more experienced the observer, the greater was the intra-observer reliability. With more vigorous training, the reliability of this modality could improve.

In our study, conventional radiographs were taken at three different beam angulations and this may be helpful in detecting vertical root fractures. The reason that conventional films were used in this study is because they are still commonly used in dental clinics, inexpensive, generally available in the market and provide high resolution images. In this study we used F-speed Eastman Kodak Insight conventional films. The F-speed films were introduced in April of 2000 as a replacement for D-speed and E-speed intraoral films for the increased speed. This film is 20% faster and has a 20% to 25% reduction in patient radiation exposure dose compared to the E-speed product, Ektaspeed Plus film (Geist and Brand, 2001; Nair and Nair, 2001; Syriopoulos et al., 2001; Ludlow et al., 2001; Bernstein et al., 2003; Alkurt et al., 2007).

In this study we used CMOS sensors in detecting vertical root fracture because most vertical root fractures occur in endodontically treated teeth and many endodontists prefer digital sensors to PSP imaging plates. The RVG 5000 sensor has a spatial

| Sensor  | 0.775 | 0.062 |
| CBCT    | 0.811 | 0.067 |

*SD: standard deviation.
There is also a study that reported that one specific CCD sensor had higher sensitivity than did a PSP plate in the detection of induced root fractures (Wenzel et al., 2005). However, another study found no significant difference between another digital CCD and film (Kositbowornchai et al., 2001). Their results were similar to our study. The resolution of digital systems has improved since those studies were published. The RVG 5000 system that we used in this study comes with a default sharpness adjustment which improved the image quality significantly.

Youssefzadeh et al., 1999 showed that the sensitivity of Medical CT was better than that of conventional film for vertical root fracture detection. We did not show a significant difference between two-dimensional conventional radiography and multi-slice CBCT. However, the effective dose from CT is still high compared with that from conventional radiography and CBCT. One study (Ludlow and Ivanovic, 2008) showed that dental CBCT is a dose-sparing technique in comparison with alternative medical CT scans for common oral and maxillofacial radiographic imaging tasks.

CONCLUSIONS

There was no significant difference between intraoral films, a high-resolution CMOS digital imaging system and CBCT in detecting vertical root fractures. However, CBCT showed the highest score in detecting vertical root fracture. Observers’ experience in interpreting CBCT plays a role in improving the accuracy of observations.

Acknowledgements

The authors would like to thank the Oral Radiology Clinic, Faculty of Dentistry, Chiang Mai University for supporting equipments for the research project; the Research Center of Faculty of Dentistry, Chiang Mai University for the use of the universal testing machine; and Grace dental care clinic, Chiang Mai, for the use of CBCT machine (Veraviewepocs 3D). We thank Prof. M. Kevin O Carroll for his assistance in editing of manuscript; Dr. Phattaranant Mahasantipiya for being one of the observers; Dr. Nopawong Luevitoonvechakij and Dr. Thepparat Khemaleelakul for their assistance in using the universal testing machine.

References

Akdeniz, BG., Grondahl, HG., and Magnusson, B. 2006.


Bernstein, DI., Clark, SJ., Scheetz, JP., Farman, AG., and Rosenson, B. 2003. Perceived quality of...


Mora, MA., Mol, A., Tyndall, DA., and Rivera, EM.


