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Effectiveness of limited cone-beam computed tomography in the detection of horizontal root fracture

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Abstract – To compare the diagnostic accuracy of conventional film radiography, charge coupled device (CCD) and photostimulable phosphor plate (PSP) digital images and limited cone-beam computed tomography in detecting simulated horizontal root fracture. Root fractures were created in the horizontal plane in 18 teeth by a mechanical force and fragments were relocated. Another 18 intact teeth with no horizontal root fracture served as a control group. Thirty-six teeth were placed in the respective empty maxillary anterior sockets of a human dry skull in groups three by three. Intraoral radiographs were obtained in three different vertical views by utilizing Eastman Kodak E-speed film, CCD sensor, RVG 5.0 Trophy and a PSP sensor Digora, Optime. Cone beam CT images were taken with a unit (3D Accuitomo; J Morita MFG. Corp, Kyoto, Japan). Three dental radiologists separately examined the intraoral film, PSP, CCD and cone beam CT images for the presence of horizontal root fracture. Specificity and sensitivity for each radiographic technique were calculated. Kappa statistics was used for assessing the agreement between observers. Chi-square statistics was used to determine whether there were differences between the systems. Results were considered significant at $P < 0.05$. Cone beam CT images revealed significantly higher sensitivities ($P < 0.05$) than the intraoral systems between which no significant differences were found. Specificities did not show any statistically significant differences between any of the four systems. The kappa values for inter-observer agreement between observers (four pairs) ranged between 0.82–0.90 for the 3DX evaluations and between 0.63–0.71 for the different types of intraoral images. Limited cone beam CT, outperformed the two-dimensional intraoral, conventional as well as digital, radiographic methods in detecting simulated horizontal root fracture.

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Root fractures, defined as fractures involving dentin, cementum and pulp are relatively uncommon among dental traumas, comprising 0.5–7% of the injuries affecting the permanent dentition (1). Horizontal root fractures are most frequently observed in the maxillary anterior region of male patients because of trauma associated with e.g. automobile accidents, sports injuries and fights. They often occur in fully erupted teeth with complete root formation (1–5). The diagnosis of horizontal root fracture is based on the radiographic demonstration of a fracture line or lines and/or mobility of the coronal segment of the tooth. A root fracture can be overlooked if the X-ray beam does not pass along the fracture line. Therefore, two or three radiographs taken at various angles are recommended (1, 6–8). The interpretation of root fracture on radiographs is problematic – particularly where displacement of the fragments has not yet occurred because of edema or granulation tissue. Pulp necrosis occurs approximately in 25% of cases after horizontal root fractures making their early detection essential. It is thus important to utilize a radiographic technique providing the best diagnostic accuracy (9, 10). Two-dimensional intraoral conventional film and digital radiography are hitherto the most common modalities to diagnose horizontal root fracture in routine clinical use.

It is possible to digitally acquire radiographic information with reduced radiation dose compared with conventional film and to enhance, store, retrieve and transfer the obtained information (11). Moreover, digital intraoral systems offer other advantages over silver halide film, including time savings, environmental waste reduction, elimination of darkroom costs and work flow benefits. Solid-state detectors – charge coupled devices (CCD) or complementary metal oxide semiconductors – and photostimulable phosphor plates (PSP) are used to produce digital images (12–16).

Any two-dimensional intraoral conventional or digital radiography systems fail to provide information regarding the third dimension of teeth and adjacent structures. Recently, cone beam computed tomography (CBCT) scanners dedicated to dentomaxillo-facial imaging became commercially available. CBCT uses a round or rectangular cone-shaped X-ray beam centered on an X-ray sensor. During a 180° to 360° rotation of the X-ray source and detector, with the midpoint of a selected volume as rotation center, a series of data is acquired that provides the raw digital data for reconstruction of the exposed volume by computer algorithm (17, 18). The use of CBCT technology in dento-maxillofacial imaging provides a number of potential advantages compared with computed tomography such as X-ray beam collimation to the area of interest, reduced effective dose and less artifacts (17–20).

Previous studies found cone beam dental CT superior to intraoral conventional film and digital radiography in detection of periapical lesions (21, 22) and in measurement of caries depth (23). Cone-beam dental CT was significantly superior to panoramic images in predicting neurovascular bundle exposure following impacted mandibular third molar extraction (24). Another study revealed subjectively superior image quality for F-speed film and storage phosphor images compared with cone beam dental CT images for the evaluation of both homogeneity and length of root fillings (25). Clinical application of cone beam tomography for diagnosis and treatment planning of dento-alveolar traumatic injuries in three selected cases was illustrated (26). To our knowledge, there are no published articles aimed at comparing cone-beam computed tomography with conventional intraoral film and digital radiography in detecting horizontal root fracture. The purpose of this study was to compare the diagnostic accuracy of conventional film radiography, CCD and PSP digital images and limited cone-beam computed tomography in detecting simulated horizontal root fractures of extracted human teeth when assessed by different examiners.

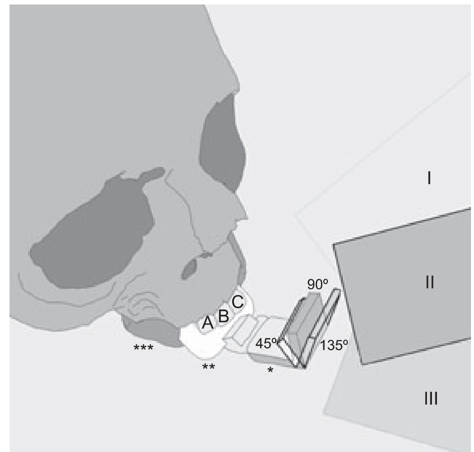

Fig. 1. Schematic drawing of the experimental design *Experimental acrylic blocks fixed to film holder forming 45°, 90° and 135° angles that allowed adjustment of the vertical angle. Cone numbers I, II and III correspond to 45°, 90° and 135° angulations, respectively. **The dental X-ray film was held in place with a fixed film holder. Teeth (A, B and C) were placed in the respective empty maxillary anterior sockets (left and right maxillary centrals and lateral) of a human dry skull in groups three by three. ***Bite block constructed by using putty impression material for each group for standardized positioning of the teeth and intraoral image receptors.

Material and methods

The experimental group consisted of 50 recently extracted human incisors (centrals and laterals) without fracture, periapical pathology, root resorption or anomaly. Root fractures were created in the horizontal plane in 18 teeth by a mechanical force using a hammer with the tooth placed on a soft foundation as described in a previous study (27). Then, two fragments from each tooth were relocated with Super Glue (Super Glue gel, 3 M; Scotch, St Paul, MN, USA). Pilot studies determined the necessary force to break the root in two fragments. Fourteen teeth roots broke in more than two fragments and were excluded from the study. Another 18 intact teeth with no horizontal root fracture served as a control group. Randomly, 18 different groups were formed with three teeth in each in order to make it as similar as possible to a regular periapical radiograph in a trauma case. Thereafter, 36 teeth were coded and placed in the respective empty maxillary anterior sockets (left and right maxillary lateral and centrals) of a human dry skull in groups three by three. The dental X-ray films and sensors were held in place with a fixed film holder (Rinn Corporation, Elgin, IL, USA) during exposure. Experimental acrylic blocks were constructed for each group forming 45°, 90° and 135° angles that allowed adjustment of the vertical angle (Fig. 1). Films and sensors were positioned, intraoral conventional and digital radiographs exposed in three different vertical views to increase the number of observations. Size 2, E-film (Eastman Kodak Co, Rochester, NY) and two digital sensors were used: CCD, RVG 5.0 (Trophy, Marne la Valle, France), sensor size 1, with $\sim$10–15 lp mm^{-1} spatial resolution and a photostimulable phosphor plate (PSP) Digora Optime (Soredex, Helsinki, Finland) offering 12.5 lp mm^{-1} spatial resolution with 4.3 s to 7.5 s read-out time (Fig. 2). Images were exposed with a Gendex Oralix DC (Gendex Dental Systems, Milan, Italy) dental X-ray machine operated at 60 kV, 7 mA with a focus-receptor distance of 25 cm and 1.5 mm Al equivalent filtration. Specimens were radiographed using exposure times of 0.64 s (conventional films), 0.24 s (CCD sensor), and 0.20 s (PSP sensors). The optimal image quality was determined by the visibility of the pulpal root canal, dentine and trabecular pattern of the bone. Analog radiographs were developed on the same day in an automatic processor XR 24 Nova (Dürr Dental, Bietigheim-Bissinger, Germany) with the use of fresh chemicals in accordance with the manufacturer's instructions. Phosphor plates were scanned immediately after exposure. For each intraoral system 54 images were produced making a total of 162.

Cone beam CT images were taken with a unit (3D Accuitomo; J Morita MFG. Corp, Kyoto, Japan) providing a cylindrical volume with height of 30 mm and width of 40 mm and a voxel size of 0.125 mm. Exposures were made with 3.0 mA, 60 kV and an exposure time of 17.5 s. The skull was placed on a horizontal plate fitted to the head support so that its occlusal plane became parallel with the plate. Using the

Fig. 2. Intraoral image obtained by photostimulable phosphor plate Digora Optime (Soredex, Helsinki, Finland). Arrow shows the radiolucent horizontal root fracture line detected on the central incisor.

light lines in displaying the X, Y and Z planes the patient chair was moved so that the X-line became placed between the central incisors, the Y line at the cuspid and the Z line at the middle of the roots. From the volume obtained after a reconstruction time of ~85 s new slice angles were chosen so that every single tooth was displayed with its root in a vertical position as seen in both the sagittal and the coronal plane. The slice thickness used was 1 mm with distances of 1 mm between their midpoints. The slices were thus contiguous (Fig. 3).

Three dental radiologists separately examined the intraoral film, PSP, CCD and cone beam tomography images for the presence of root fractures in a subdued room in different sessions. All had access to the three views simultaneously for the intraoral techniques. Radiolucent lines in the roots were regarded as fractures. An all or nothing response was preferred for the evaluation of the presence of a fracture. The time allocated for the observations was not restricted. Conventional radiographs were evaluated at random against a light box. Observers were allowed to use a magnifying glass. Digital intraoral images were all captured and stored in their own systems' software. The images were analyzed on a Dell Workstation PWS 350 (Dell Inc., Round Rock, TX, USA), Intel® Pentium, 2.66 GHz, 1.047.536 KB RAM equipped with graphic-card Radeon VE ATI Technologies Inc. and a Dell-monitor (size 18 inches) with Trinitron tube, 1024 × 768 pixels. Adjustment of contrast and brightness could be done, if considered necessary, using the inbuilt image processing tools.

Horizontal root fracture/non-fracture assessments were categorized as true-positive – correct identification of a fractured root; true-negative – correct identification of a non-fractured root; false-positive – identification of a fracture in a non-fractured root; and false-negative – no identification of a fracture in a fractured root. Specificity and sensitivity for each radiographic technique were calculated. Kappa statistics was used for assessing the agreement between observers. Chi-square statistics was used to determine whether there were differences between the systems. Results were considered significant at $P < 0.05$.

Results

Table 1 shows the mean sensitivities and specificities calculated for intraoral conventional film, digital sensors and cone beam tomography images assessed by the three observers. Considering the observer means, cone beam dental CT images revealed significantly higher sensitivities ($P < 0.05$) than the intraoral systems between which no significant differences were found. Specificities did not show any statistically significant differences between any of the four systems.

The kappa values for inter-observer agreement between observers (four pairs) ranged between 0.82–0.90 for the 3DX evaluations and between 0.63–0.71 for the different types of intraoral images. While being substantial for the intraoral images it was almost perfect for the 3DX images.

Discussion

The present study compared intraoral conventional film, intraoral PSP and CCD detectors and dental cone beam CT to detect simulated horizontal root fracture in extracted human teeth. Dental cone beam CT (Accuitomo; J Morita) chosen for this study was proven to be more accurate than the other two dimensional intraoral techniques. In actual clinical conditions, root fractures can be misdiagnosed or undetected because of anatomic features, superimposition of dental structures and artifacts when two dimensional techniques are utilized. In intraoral radiography, dental structures are compressed in a two-dimensional image. On the other hand, cone-beam CT units provide information in axial, coronal and cross-sectional sections making it possible for the clinician to detect fractures which are not diagnosed or misdiagnosed in routine intraoral techniques.

Obviously, it is difficult to place teeth from different individuals into dry sockets of another dry skull. In the present study we formed random groups according to the size of the various teeth and sockets. Therefore, appropriate teeth were placed in the appropriate sockets. In real clinical conditions, three to four teeth can be observed in intraoral images. Also, with the CBCT system used in the present study we could focus on a limited area as small as a periapical radiographic view. In addition, the real effect of superimposition of adjacent

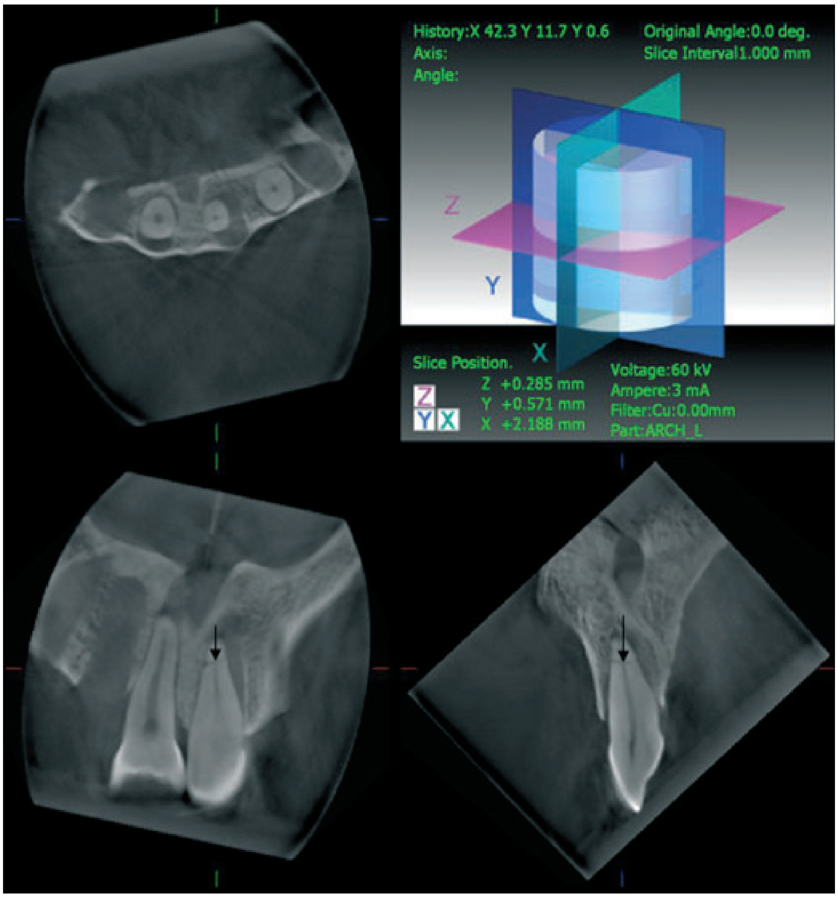

Fig. 3. Cone beam CT images obtained by using a unit (3D Accuitomo; J Morita MFG. Corp, Kyoto, Japan) can be seen. Arrows show the radioluscent fracture lines detected on coronal (left) and cross-sectional (right) views.

dental structures was simulated by imaging three teeth at the same time instead of imaging them one by one.

Recently (27), a high resolution charge-coupled device (RVG-ui; 15–20 lp mm^{-1}) sensor was shown to be superior to medium resolution phosphor plate (Digora; 8 lp mm^{-1}) receptor in detecting artificial horizontal root fracture. This was the result of the difference in spatial resolution between the two systems. Three different projections evaluated at the same time revealed the best results. Mean observer sensitivity was 0.65 and mean observer specificity was 0.90 for CCD. Our study revealed relatively higher sensitivities (CCD, 0.68; PSP, 0.71) and higher specificities (CCD, 0.97; PSP, 0.95). Relatively higher mean sensitivity and specificity obtained for digital intraoral systems could be due to the fact that no soft tissue equivalent was used in the present study. Besides, experienced oral radiologists in digital image interpretation acted as observers. The two intraoral digital radiography systems chosen for this study performed as well as conventional film in terms of sensitivity and specificity. It is suggested that intraoral digital radiographs taken from three different projections may help to detect suspected horizontal root fracture with the advantages of acceptable effective radiation dose, instant image acquisition and image enhancement tools.

Other studies mainly focused on the detection of vertically fractured teeth using different imaging modalities (28–32). Sensitivities for horizontal root fracture detection are higher as the radiographic diagnosis of horizontal root fracture is easier than that of vertical root fracture because of absence of masking effect of root canal filling and it is easier to send the central X-ray beam parallel to the fracture line in horizontally

Table 1. Mean sensitivities and specificities calculated for intraoral conventional film (Kodak, E speed), CCD sensor (RVG, Trophy), PSP sensor (Digora) and cone beam tomography 3DX images (Accuitomo) assessed by the three observers

	Observer 1		Observer 2		Observer 3		Mean	
	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
Digora	0.71	0.87	0.79	1.0	0.63	0.97	0.71	0.95
CCD	0.71	0.97	0.75	0.97	0.58	0.97	0.68	0.97
FILM	0.79	1.0	0.79	1.0	0.63	0.87	0.74	0.96
3 DX	0.92	0.97	0.92	0.97	0.92	0.97	0.92	0.97

fractured roots. It is reasonable to assume that evaluating the images from three different radiographic projections improved the visualization in the present study.

The effectiveness of tuned aperture computed tomography (TACT) has been evaluated (28–30). This uses arbitrary two-dimensional radiographs to reconstruct three-dimensional by specially designed software (30) in the detection of artificially induced root fractures. Nair et al. (28). compared TACT and direct digital radiography in the detection of artificially induced vertical radicular fractures of cadaver teeth and concluded that TACT is the imaging modality of choice for vertical root fractures in endodontically treated teeth. For direct digital sensor an average sensitivity (0.28) and specificity (0.33) was found among eight observers. There were great discrepancies between observers for sensitivities ranging from 0.03 to 0.55 and for specificities from 0.12 to 0.69. Iteratively restored TACT images (related to the TACT system and software) showed an average sensitivity and specificity of 0.55 and 0.82, respectively, across all observers, with variations among observers. However, TACT modality can not be commonly used and is still not commercially available.

In an *in vivo* study (31) that focused on the diagnostic value of CT in the detection of vertical root fracture, sensitivity was 0.23 for conventional dental radiography and 0.70 for CT (average for two observers). The low sensitivity for intraoral conventional radiography can be explained by the limitations of the actual clinical conditions and the difficulty in detecting vertical root fracture. Hannig et al. (32). proposed three-dimensional flat panel volume detector computer tomograph (FD-VCT) system for detection of vertical root fracture. High radiation dose, high cost and lack of availability may preclude the use of conventional CT in each case.

In the present study, mean sensitivity was found to be 0.92 and specificity 0.97 for dental cone beam CT in detection of horizontal root fracture. Dental cone beam CT chosen for this study outperformed the 2-dimensional intraoral, conventional as well as digital, radiographic methods in detecting simulated horizontal root fracture. In this study, fragments were glued tightly together and relocated in their original position. This made the appearance of the fracture lines similar to that in immediate post-trauma cases and thus difficult to detect. In spite of this, dental cone beam CT provided highly accurate results. It is apparent that dental cone beam CT can provide useful information regarding the diagnosis of horizontal root fracture. Horizontal root fracture can be detected sooner using cone-beam CT compared with periapical views, and the fracture can be assessed in coronal, axial and cross-sectional views.

Published reports indicate that the effective dose from the cone beam CT unit we worked with range between 11 and 77 μSv depending on the size of the volume used, the exposure parameters chosen and the region examined. It is lower for the upper central incisor region than for other jaw regions. In this region it is also possible to use lower exposure values than in others (33). The effective doses for conventional imaging are in the range of 1–8.3 μSv for an intraoral exam and 4–30 μSv for panoramic examination (34). Although cone-beam CT is an innovative and promising technology, effective radiation doses are still higher than with conventional intra-oral and panoramic imaging. Therefore, we still do not have enough of proof to say that cone-beam CT should be our method of choice in all dental trauma cases. Currently, cone-beam CT should only be considered when conventional radiographic techniques fail to provide useful information for diagnosing horizontal root fracture.

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