RESEARCH

Radiographic detection of artificially created horizontal root fracture using different cone beam CT units with small fields of view

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Objectives: To compare limited cone beam computerized tomography (CBCT) units with different field of views (FOVs) and voxel sizes in detecting artificially created horizontal root fracture (HRF) in extracted human teeth.

Methods: Artificial HRF was created in the horizontal plane in 40 teeth. Another 40 intact teeth served as a control group. 80 teeth were placed in the respective maxillary anterior sockets of a human dry skull in groups. Six image sets were obtained: (1) Accuitomo 170, 40 × 40 mm FOV (0.080 mm³); (2) Accuitomo 170, 60 × 60 mm FOV (0.125 mm³); (3) Kodak 9000, 50 × 37 mm FOV (0.076 mm³); (4) Kodak 9000, 50 × 37 mm FOV (0.100 mm³); (5) Vatech Pax-Duo3D 50 × 50 mm FOV (0.080 mm³) and (6) Vatech Pax-Duo3D 85 × 85 mm FOV (0.120 mm³). Images were evaluated twice by five observers. Kappa values were calculated for observer agreement. Areas under the receiver operating characteristic (ROC) curves (Az values) were calculated, and the Az values for each image type were compared using *t*-tests ($\alpha = 0.05$).

Results: Intraobserver kappa coefficients ranged from 0.81 to 0.95 for the Accuitomo 170 images, from 0.80 to 0.92 for the Kodak 9000 images and from 0.76 to 0.95 for Vatech PanX-Duo3D. The Az values for different image types and observers ranged from 0.93 to 0.97 for Accuitomo 170 images, from 0.93 to 0.98 for Kodak 9000 images and from 0.93 to 0.97 for the Vatech PanX-Duo3D images. No statistically significant differences ($p > 0.05$) were found between the Az values.

Conclusions: Limited CBCT units performed similarly in detecting simulated HRF. *Dentomaxillofacial Radiology* (2013) 42, 20120261. doi: 10.1259/dmfr.20120261

Cite this article as: Kamburoğlu K, Önder B, Murat S, Avsever H, Yüksel S, Paksoy CS. Radiographic detection of artificially created horizontal root fracture using different cone beam CT units with small fields of view. *Dentomaxillofac Radiol* 2013; 42: 20120261.

Keywords: horizontal root fracture; CBCT; detection; radiography

Introduction

Horizontal root fracture (HRF) is most frequently observed in the maxillary anterior region of male patients owing to trauma associated with accidents, sports injuries and fights. They often occur in fully erupted teeth with complete root formation. Pulp necrosis occurs approximately in 25% of cases after HRF, making their early detection essential. The diagnosis of HRF is based on the

radiographic demonstration of a fracture line or lines and/or mobility of the coronal segment of the tooth.¹⁻³

Radiography combined with clinical examination is the only method available for the evaluation of HRF in routine dental practice. Intraoral imaging, whether digital or film, continues to provide the best spatial resolution of any imaging method currently available.⁴⁻⁶ However, because fracture can be overlooked when the X-ray beam does not pass along the fracture line, in many cases, two or three intraoral radiographs taken from different angles are recommended. The interpretation of root fracture on intraoral radiographs can be problematic,

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Received 17 July 2012; revised 9 September 2012; accepted 11 September 2012

particularly where displacement of the fragments has not yet occurred owing to edema or granulation tissue.⁷

Cone beam computerized tomography (CBCT) was developed and introduced in response to the high demand for a technique that could provide three-dimensional (3D) data at a lower cost and with lower radiation doses than the conventional CT used in medical radiology. Whereas conventional CT scanners emit a fan-shaped X-ray beam and use primary reconstruction of data to produce axial slices from which orthogonal planar images are generated using secondary reconstruction, CBCT systems operate by focusing a cone-shaped beam on a two-dimensional (2D) detector that performs one pass or less around the patient's head and use multiple-basis data projections to secondarily reconstruct orthogonal images. The use of special cone beam algorithms allows not only conventional axial plane reconstructions but also multiplanar, reformatted 2D, 3D and panoramic reconstructions as well.^{8–10}

The technology with potentially the greatest impact on imaging in maxillofacial and dentoalveolar trauma in the next decade is CBCT.⁴ Limited CBCT (PSR 9000N; Asahi Roentgen Co., Kyoto, Japan) with 40×41 mm field of view (FOV) was more useful than multidetector helical computerized tomography at slice thicknesses of 0.63 mm and 1.25 mm for diagnostic imaging of horizontal tooth root fracture.¹¹ In a previous study, we found that limited FOV Accutomo 80 CBCT unit (Morita, Tokyo, Japan) images obtained with a 4×4 cm FOV and 0.125 mm voxel size were significantly superior to intraoral images taken from different angulations in detecting HRF *ex vivo*.⁷ Similarly, in another study, the diagnosis of the location and angulation of root fractures based on limited CBCT imaging differed significantly from diagnostic procedures based on intraoral radiographs alone.¹²

New technological specifications and settings include multiple FOVs and voxels that can better address a variety of specific tasks and imaging that can be conducted with the patient in supine, seated or standing positions. The availability of different FOVs makes it possible to select the most appropriate FOV for a specific application. FOV is the term used to refer to the scan volume of a particular CBCT unit. FOV is determined by detector size and shape, beam projection geometry and beam collimation, which limits radiation exposure to a particular region of interest. CBCT units are classified based on the FOV size as small-, medium- or large-volume units. Because the amount of X-ray scatter, or “noise”, reduces with decreases in FOV, small-volume units tend to offer the highest image resolution.^{8–10}

Voxel size is of paramount importance in terms of quality and scanning and reconstruction times of CBCT images. A “voxel” describes the smallest distinguishable box-shaped part of a 3D image. In CBCT imaging, voxels are isotropic (equal in all dimensions) and range from 0.4 mm^3 to as small as 0.075 mm^3 . Because voxels are isotropic, images can be constructed in any plane with high fidelity. In theory, CBCT can improve the

spatial resolution of high-contrast structures in any chosen viewing plane.^{8–10} The influence of voxel size in detecting HRF was investigated, and the use of high resolution CBCT images in the detection of HRF was suggested. High-resolution (0.125 mm voxel size) i-Cat[®] (Imaging Sciences Int., Hatfield, PA) CBCT images resulted in an increase in sensitivity without jeopardizing specificity for detection of HRF compared with lower resolution (0.25 mm voxel size) CBCT images, which were not more accurate than periapical photo-stimulable phosphor-coated plates.¹³

As can be seen, CBCT images obtained with limited FOV at a small voxel size are recommended in the detection of HRF. Hitherto, no previous study compared different CBCT units in the detection of HRF. This study aimed to compare different limited CBCT units by using different FOVs and voxel sizes in the detection of artificially created HRF in extracted human teeth *ex vivo*.

Materials and methods

Extracted single-rooted maxillary teeth were obtained from individuals who gave informed consent to donate their extracted teeth for research purposes. The experimental group consisted of 80 recently extracted human maxillary incisors (centrals and laterals) without fracture, periapical pathology, root resorption or anomaly. Root fractures were created in the horizontal plane in 40 teeth by a mechanical force using a hammer with the tooth placed on a soft foundation. Then, two fragments from each tooth were relocated with glue (Figure 1). Another 40 intact teeth with no HRF served as a control group. Thereafter, 80 teeth were placed in the respective empty maxillary anterior sockets (left and right maxillary

Figure 1 Root fractures were created in the horizontal plane and then the two fragments were relocated with glue

lateral and centrals) of a human dry skull in groups four by four. The dry skull was covered by red wax to simulate soft tissue (Figure 2).

Images were obtained from three different CBCT units:

1. 3D Accuitomo 170 (3D Accuitomo; J Morita Mfg. Corp., Kyoto, Japan) with a complementary metal oxide semiconductor (CMOS) flat panel detector offering five different FOVs— 40×40 mm, 60×60 mm, 80×80 mm, 100×100 mm and 170×120 mm—with voxel sizes ranging from 0.08 mm to 0.250 mm
2. Kodak 9000 3D (Eastman Kodak Co., Rochester, NY) CMOS sensor with an optical fiber, offering a single 50×37 mm FOV with voxel sizes ranging from 0.076 mm to 0.250 mm
3. Vatech Pax-Duo3D Pano/CBCT (Vatech, Seoul, Republic of Korea) system with a 12×8.5 cm amorphous silicon flat-panel image detector offering FOVs between 50×50 mm and 150×135 mm with voxel sizes ranging from 0.08 mm to 0.3 mm.

A total of six image sets were obtained as follows:

- (1) Accuitomo 170, 40×40 mm FOV (0.080 mm^3);
- (2) Accuitomo 170, 60×60 mm FOV (0.125 mm^3);
- (3) Kodak 9000, 50×37 mm FOV (0.076 mm^3);
- (4) Kodak 9000, 50×37 mm FOV (0.100 mm^3);
- (5) Vatech Pax-Duo3D 50×50 mm FOV (0.080 mm^3) and
- (6) Vatech Pax-Duo3D 85×85 mm FOV (0.120 mm^3).

For all imaging modalities, exposure parameters were determined based on pilot studies conducted to ensure optimal image quality with good visibility of the trabecular pattern, and enamel, dentine and pulpal space. With the Accuitomo 170 system, images were obtained at 90 kV and 5.0 mA, with an exposure time of 17.5 s. With Kodak 9000 extraoral imaging system, images were obtained at 70 kVp and 10 mA, with an exposure time of 10.8 s. With the Vatech system, images were obtained

at 90 kVp and 7 mA, with an exposure time of 35 s. Axial scans and multiplanar reconstructions were obtained, and volumetric data were reconstructed to provide serial cross-sectional views. All images were evaluated separately by five calibrated observers (three experienced DMFR specialists and two PhD students) using the imaging systems' own software and enhancement tools in a random order (i-Dixel 2.0/One Data Viewer/One Volume Viewer for Accuitomo, Kodak Imaging Software for Kodak 9000 and EasyDent/Ez3D for Vatech). Images were viewed in a dimly lit room on a 15-inch Toshiba Qosmio monitor (Toshiba, Tokyo, Japan) set at a screen resolution of 1920×1080 and 32-bit colour depth at 5 day intervals, and evaluations of each image set were repeated 1 month after the initial viewings. All teeth were randomly evaluated for the presence/absence of HRF and scored using a five-point scale as follows: 1 = fracture definitely present, 2 = fracture probably present, 3 = uncertain/unable to tell, 4 = fracture probably not present and 5 = fracture definitely not present (Figures 3–5).

Kappa values were calculated to assess intra- and interobserver agreement according to the following criteria: <0.10 , no agreement; 0.10 – 0.40 , poor agreement; 0.41 – 0.60 , significant agreement; 0.61 – 0.80 , strong agreement; and 0.81 – 1.00 , excellent agreement. The areas under the receiver operating characteristic (ROC) curves (Az values) were calculated, and the Az values for each image type were compared using *t*-tests, with a significance level of $\alpha = 0.05$. In addition, sensitivity, specificity, predictive values and false-positive ratios were calculated for each imaging method.

Results

Table 1 shows the intraobserver kappa coefficients calculated for each observer by image type. Intraobserver kappa

Figure 2 20 different groups, each one comprising four teeth, were formed, and 80 teeth were placed in the respective empty maxillary anterior sockets (left and right maxillary lateral and centrals) of a human dry skull in groups, four by four. Dry skull was covered by red wax to simulate soft tissue

Figure 3 Cone beam CT images obtained by Accutomo 170 (J Morita Mfg. Corp., Kyoto, Japan) with 40×40 mm field of view (FOV) and 0.080 mm^3 . Arrows show horizontal root fracture on coronal (left) and cross-sectional (right) views

coefficients ranged from 0.81 to 0.95 for the Accutomo 170 images, from 0.80 to 0.92 for the Kodak 9000 images and from 0.76 to 0.95 for Vatech PanX-Duo3D images, suggesting excellent intraobserver agreement.

Tables 2 and 3 show interobserver kappa coefficients for the first and second readings, respectively, by image type. In general, strong and excellent interobserver agreement was found for the first and second readings

Figure 4 Cone beam CT images obtained by Kodak 9000 (Eastman Kodak Co., Rochester, NY) with 50×37 mm field of view (FOV) and 0.076 mm^3 . Arrows show horizontal root fracture on coronal (left) and cross-sectional (right) views

Figure 5 Cone beam CT images obtained by Vatech Pax-Duo3D (Vatech, Seoul, Republic of Korea) with 50 × 50 mm field of view and 0.080 mm³. Arrows show horizontal root fracture on coronal (left) and cross-sectional (right) views

for the Accuitomo 170 images (from 0.52 to 0.91) and Kodak 9000 images (from 0.52 to 0.86). Significant and strong interobserver agreement was found for the first and second readings for the Vatech PanX-Duo3D images (from 0.45 to 0.91).

Considering the excellent intraobserver agreement, only first readings of the observers were taken into consideration for Az calculations. The areas under the ROC curves (Az values) for the different observers, first readings and image types were calculated and are given in Table 4. This table shows Az values, their standard errors (SE), 95% confidence intervals (CI) and significance levels (*p*) for each observer for the first reading. The Az values of first readings of all five observers were extremely high. The Az values for different image types and observers ranged from 0.93 to 0.97 for Accuitomo 170 images, from 0.93 to 0.98 for Kodak 9000 images and from 0.93 to 0.97 for the Vatech PanX-Duo3D images. No statistically significant differences (*p*>0.05)

were found between any of the Az values obtained from the limited CBCT images for each observer.

Figure 6 shows the ROC curve for the first reading of Observer 5 for each image type.

Table 5 shows sensitivity (Se), specificity (Sp), positive predictive value (PPV), negative predictive value (NPV) and false positive ratio (FPR) for each observer and their first reading. Extremely high sensitivity, specificity and predictive values were found.

Discussion

The present study compared different limited CBCT units by using a small FOV and small voxel sizes. 3D Accuitomo 170, Kodak 9000 3D and Vatech Pax-Duo3D units were chosen because of their ability to offer small FOVs. In addition, they are available in our city and it can be said that they are among the more commonly

Table 1 Intraobserver agreement calculated for each observer by image type

	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5
	Weighted Kappa-SE	Weighted Kappa-SE	Weighted Kappa-SE	Weighted Kappa-SE	Weighted Kappa-SE
Imaging modality					
Accuitomo 170, 40×40 mm FOV (0.080 mm ³)	0.91–0.061	0.95–0.047	0.82–0.080	0.82–0.076	0.91–0.060
Accuitomo 170, 60×60 mm FOV (0.125 mm ³)	0.83–0.092	0.91–0.060	0.81–0.088	0.84–0.087	0.83–0.087
Kodak 9000, 50×37 mm FOV (0.076 mm ³)	0.87–0.070	0.90–0.063	0.83–0.073	0.83–0.076	0.87–0.070
Kodak 9000, 50×37 mm FOV (0.100 mm ³)	0.89–0.060	0.86–0.075	0.92–0.053	0.88–0.064	0.80–0.078
Vatech Pax-Duo3D 50×50 mm FOV (0.080 mm ³)	0.85–0.070	0.82–0.080	0.95–0.047	0.80–0.080	0.84–0.074
Vatech Pax-Duo3D 85×85 mm FOV (0.120 mm ³)	0.82–0.060	0.86–0.070	0.88–0.063	0.76–0.082	0.80–0.076

FOV, field of view; SE, standard error.
Accuitomo 170 is manufactured by J Morita Mfg. Corp., Kyoto, Japan; Kodak 9000 by Eastman Kodak Co., Rochester, NY; and Vatech Pax-Duo3D by Vatech, Seoul, Republic of Korea.

Table 2 Interobserver Kappa coefficients among observers (Obs) for the first readings

Imaging modality	Obs1–Obs2		Obs1–Obs3		Obs1–Obs4		Obs1–Obs5		Obs2–Obs3		Obs2–Obs4		Obs2–Obs5		Obs3–Obs4		Obs3–Obs5		Obs4–Obs5	
	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE
Accutomo 170, 40×40 mm FOV (0.080 mm ³)	0.71–0.060	0.76–0.057	0.66–0.066	0.66–0.066	0.66–0.066	0.66–0.066	0.89–0.044	0.89–0.044	0.75–0.060	0.75–0.060	0.68–0.064	0.68–0.064	0.78–0.056	0.78–0.056	0.71–0.067	0.71–0.067	0.82–0.052	0.82–0.052	0.74–0.064	0.74–0.064
Accutomo 170, 60×60 mm FOV (0.125 mm ³)	0.71–0.062	0.66–0.061	0.63–0.064	0.63–0.064	0.63–0.064	0.63–0.064	0.81–0.055	0.81–0.055	0.71–0.063	0.71–0.063	0.65–0.065	0.65–0.065	0.69–0.062	0.69–0.062	0.60–0.066	0.60–0.066	0.78–0.063	0.78–0.063	0.57–0.065	0.57–0.065
Kodak 9000, 50×37 mm FOV (0.076 mm ³)	0.73–0.062	0.75–0.061	0.71–0.061	0.71–0.061	0.71–0.061	0.71–0.061	0.83–0.053	0.83–0.053	0.77–0.060	0.77–0.060	0.65–0.064	0.65–0.064	0.80–0.056	0.80–0.056	0.74–0.062	0.74–0.062	0.82–0.057	0.82–0.057	0.72–0.062	0.72–0.062
Kodak 9000, 50×37 mm FOV (0.100 mm ³)	0.69–0.063	0.72–0.060	0.67–0.062	0.67–0.062	0.67–0.062	0.67–0.062	0.78–0.065	0.78–0.065	0.66–0.065	0.66–0.065	0.58–0.061	0.58–0.061	0.68–0.066	0.68–0.066	0.55–0.064	0.55–0.064	0.73–0.067	0.73–0.067	0.55–0.068	0.55–0.068
Vatech Pax-Duo 3D 50×50 mm FOV (0.080 mm ³)	0.78–0.060	0.76–0.062	0.69–0.063	0.69–0.063	0.69–0.063	0.69–0.063	0.91–0.040	0.91–0.040	0.77–0.050	0.77–0.050	0.63–0.063	0.63–0.063	0.74–0.061	0.74–0.061	0.61–0.064	0.61–0.064	0.72–0.062	0.72–0.062	0.69–0.062	0.69–0.062
Vatech Pax-Duo3D 85×85 mm FOV (0.120 mm ³)	0.60–0.064	0.58–0.065	0.65–0.065	0.65–0.065	0.65–0.065	0.65–0.065	0.78–0.055	0.78–0.055	0.69–0.062	0.69–0.062	0.51–0.065	0.51–0.065	0.48–0.064	0.48–0.064	0.49–0.063	0.49–0.063	0.64–0.064	0.64–0.064	0.53–0.069	0.53–0.069

FOV, field of view; SE, standard error.

Accutomo 170 is manufactured by J Morita Mfg. Corp., Kyoto, Japan; Kodak 9000 by Eastman Kodak Co., Rochester, NY; and Vatech Pax-Duo3D by Vatech, Seoul, Republic of Korea.

Table 3 Interobserver Kappa coefficients among observers (Obs) for the second readings

Imaging modality	Obs1–Obs2		Obs1–Obs3		Obs1–Obs4		Obs1–Obs5		Obs2–Obs3		Obs2–Obs4		Obs2–Obs5		Obs3–Obs4		Obs3–Obs5		Obs4–Obs5	
	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE	Weighted	Kappa-SE
Accutomo 170, 40×40 mm FOV (0.080 mm ³)	0.85–0.079	0.91–0.063	0.89–0.084	0.89–0.084	0.77–0.087	0.77–0.087	0.82–0.079	0.82–0.079	0.85–0.079	0.85–0.079	0.72–0.094	0.72–0.094	0.81–0.082	0.81–0.082	0.77–0.086	0.77–0.086	0.82–0.079	0.82–0.079	0.78–0.085	0.78–0.085
Accutomo 170, 60×60 mm FOV (0.125 mm ³)	0.68–0.083	0.89–0.084	0.69–0.094	0.69–0.094	0.69–0.094	0.69–0.094	0.79–0.092	0.79–0.092	0.82–0.079	0.82–0.079	0.73–0.092	0.73–0.092	0.63–0.090	0.63–0.090	0.65–0.098	0.65–0.098	0.68–0.088	0.68–0.088	0.52–0.094	0.52–0.094
Kodak 9000, 50×37 mm FOV (0.076 mm ³)	0.86–0.075	0.78–0.081	0.73–0.090	0.73–0.090	0.73–0.090	0.73–0.090	0.78–0.081	0.78–0.081	0.77–0.085	0.77–0.085	0.72–0.094	0.72–0.094	0.77–0.087	0.77–0.087	0.74–0.090	0.74–0.090	0.75–0.085	0.75–0.085	0.74–0.088	0.74–0.088
Kodak 9000, 50×37 mm FOV (0.100 mm ³)	0.66–0.089	0.71–0.087	0.60–0.092	0.60–0.092	0.60–0.092	0.60–0.092	0.75–0.087	0.75–0.087	0.60–0.089	0.60–0.089	0.62–0.094	0.62–0.094	0.55–0.095	0.55–0.095	0.52–0.095	0.52–0.095	0.55–0.091	0.55–0.091	0.53–0.097	0.53–0.097
Vatech Pax-Duo3D 50×50 mm FOV (0.080 mm ³)	0.77–0.088	0.91–0.063	0.75–0.085	0.75–0.085	0.75–0.085	0.75–0.085	0.75–0.083	0.75–0.083	0.86–0.076	0.86–0.076	0.67–0.093	0.67–0.093	0.59–0.095	0.59–0.095	0.70–0.088	0.70–0.088	0.70–0.087	0.70–0.087	0.57–0.092	0.57–0.092
Vatech Pax-Duo3D 85×85 mm FOV (0.120 mm ³)	0.63–0.086	0.76–0.098	0.62–0.094	0.62–0.094	0.62–0.094	0.62–0.094	0.70–0.086	0.70–0.086	0.64–0.091	0.64–0.091	0.60–0.085	0.60–0.085	0.45–0.083	0.45–0.083	0.56–0.096	0.56–0.096	0.55–0.097	0.55–0.097	0.47–0.099	0.47–0.099

FOV, field of view; SE, standard error.

Accutomo 170 is manufactured by J Morita Mfg. Corp., Kyoto, Japan; Kodak 9000 by Eastman Kodak Co., Rochester, NY; and Vatech Pax-Duo3D by Vatech, Seoul, Republic of Korea.

Table 4 Az values, their standard errors (SE), 95% confidence intervals (CI) and significance levels (*p*) for each observer for the first reading

Imaging modality	Observer 1	Observer 2	Observer 3	Observer 4	Observer 5
	Az-SE	Az-SE	Az-SE	Az-SE	Az-SE
	95% CI	95% CI	95% CI	95% CI	95% CI
	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>	<i>p</i>
Accuitomo 170, 40×40 mm FOV (0.080 mm ³)	0.96 0.91–1.0 <0.001	0.97 0.93–1.0 <0.001	0.96 0.91–1.0 <0.001	0.94 0.87–0.99 <0.001	0.96 0.91–1.0 <0.001
Accuitomo 170, 60×60 mm FOV (0.125 mm ³)	0.94 0.89–1.0 <0.001	0.97 0.92–1.0 <0.001	0.93 0.86–0.99 <0.001	0.94 0.88–0.99 <0.001	0.95 0.90–1.0 <0.001
Kodak 9000, 50×37 mm FOV (0.076 mm ³)	0.97 0.93–1.0 <0.001	0.97 0.93–1.0 <0.001	0.98 0.95–1.0 <0.001	0.96 0.91–1.0 <0.001	0.97 0.93–1.0 <0.001
Kodak 9000, 50×37 mm FOV (0.100 mm ³)	0.98 0.95–1.0 <0.001	0.95 0.89–1.0 <0.001	0.98 0.95–1.0 <0.001	0.96 0.91–1.0 <0.001	0.93 0.86–0.99 <0.001
Vatech Pax-Duo3D 50×50 mm FOV (0.080 mm ³)	0.97 0.93–1.0 <0.001	0.97 0.93–1.0 <0.001	0.96 0.91–1.0 <0.001	0.95 0.89–1.0 <0.001	0.97 0.93–1.0 <0.001
Vatech Pax-Duo3D 85×85 mm FOV (0.120 mm ³)	0.97 0.93–1.0 <0.001	0.95 0.89–1.0 <0.001	0.96 0.92–1.0 <0.001	0.93 0.87–0.99 <0.001	0.94 0.88–0.99 <0.001

CI, confidence interval; FOV, field of view.

Accuitomo 170 is manufactured by J Morita Mfg. Corp., Kyoto, Japan; Kodak 9000 by Eastman Kodak Co., Rochester, NY; and Vatech Pax-Duo3D by Vatech, Seoul, Republic of Korea.

used units in the world. No difference was found between any of the images obtained by different units at different FOVs and voxels. Instead of exporting images into viewing software, dedicated software of

CBCT units were utilized, since software versatility is very important in terms of diagnostic radiology, and it is an integral part of CBCT performance. CBCT images obtained at different voxel sizes were assessed, since

Observer 5

Figure 6 Receiver operating characteristic (ROC) curve for the first reading of Observer 5 for each image type. Accuitomo 170 is manufactured by J Morita Mfg. Corp., Kyoto, Japan; Kodak 9000 by Eastman Kodak Co., Rochester, NY; and Vatech Pax-Duo3D by Vatech, Seoul, Republic of Korea.

Table 5 Sensitivity (Se), Specificity (Sp), positive predictive value (PPV), negative predictive value (NPV) and false-positive ratio (FPR) for each observer and their first reading

Imaging modality	Observer 1				
	Se	Sp	PPV	NPV	FPR
Accuitomo 170, 40×40 mm FOV (0.080 mm ³)	0.96	0.95	0.95	0.96	0.05
Accuitomo 170, 60×60 mm FOV (0.125 mm ³)	0.88	0.98	0.98	0.89	0.02
Kodak 9000, 50×37 mm FOV (0.076 mm ³)	0.98	0.98	0.98	0.98	0.02
Kodak 9000, 50×37 mm FOV (0.100 mm ³)	0.98	0.98	0.98	0.98	0.02
Vatech Pax-Duo3D 50×50 mm FOV (0.080 mm ³)	0.98	0.98	0.98	0.98	0.02
Vatech Pax-Duo3D 85×85 mm FOV (0.120 mm ³)	0.98	0.88	0.89	0.98	0.12

Imaging modality	Observer 2				
	Se	Sp	PPV	NPV	FPR
Accuitomo 170, 40×40 mm FOV (0.080 mm ³)	0.95	0.98	0.98	0.95	0.05
Accuitomo 170, 60×60 mm FOV (0.125 mm ³)	0.95	0.93	0.93	0.95	0.05
Kodak 9000, 50×37 mm FOV (0.076 mm ³)	0.95	0.98	0.98	0.95	0.05
Kodak 9000, 50×37 mm FOV (0.100 mm ³)	0.93	0.98	0.98	0.93	0.07
Vatech Pax-Duo3D 50×50 mm FOV (0.080 mm ³)	0.98	0.93	0.93	0.98	0.02
Vatech Pax-Duo3D 85×85 mm FOV (0.120 mm ³)	0.83	1.0	1.0	0.85	0.17

Imaging modality	Observer 3				
	Se	Sp	PPV	NPV	FPR
Accuitomo 170, 40×40 mm FOV (0.080 mm ³)	0.98	0.93	0.93	0.98	0.07
Accuitomo 170, 60×60 mm FOV (0.125 mm ³)	0.90	0.93	0.93	0.91	0.07
Kodak 9000, 50×37 mm FOV (0.076 mm ³)	0.98	1.0	1.0	0.98	0
Kodak 9000, 50×37 mm FOV (0.100 mm ³)	0.98	0.98	0.98	0.98	0.02
Vatech Pax-Duo3D 50×50 mm FOV (0.080 mm ³)	0.95	0.95	0.95	0.95	0.05
Vatech Pax-Duo3D 85×85 mm FOV (0.120 mm ³)	0.93	0.95	0.95	0.93	0.05

Imaging modality	Observer 4				
	Se	Sp	PPV	NPV	FPR
Accuitomo 170, 40×40 mm FOV (0.080 mm ³)	0.98	0.90	0.91	0.98	0.10
Accuitomo 170, 60×60 mm FOV (0.125 mm ³)	0.93	0.93	0.93	0.93	0.07
Kodak 9000, 50×37 mm FOV (0.076 mm ³)	0.98	0.95	0.95	0.98	0.05
Kodak 9000, 50×37 mm FOV (0.100 mm ³)	0.95	0.98	0.98	0.95	0.02
Vatech Pax-Duo3D 50×50 mm FOV (0.080 mm ³)	0.98	0.93	0.93	0.98	0.07
Vatech Pax-Duo3D 85×85 mm FOV (0.120 mm ³)	0.83	0.95	0.94	0.85	0.05

Imaging modality	Observer 5				
	Se	Sp	PPV	NPV	FPR
Accuitomo 170, 40×40 mm FOV (0.080 mm ³)	0.98	0.95	0.95	0.98	0.05
Accuitomo 170, 60×60 mm FOV (0.125 mm ³)	0.90	0.95	0.95	0.90	0.05
Kodak 9000, 50×37 mm FOV (0.076 mm ³)	0.95	0.98	0.98	0.95	0.02
Kodak 9000, 50×37 mm FOV (0.100 mm ³)	0.88	0.93	0.93	0.89	0.07
Vatech Pax-Duo3D 50×50 mm FOV (0.080 mm ³)	0.98	0.98	0.98	0.98	0.02
Vatech Pax-Duo3D 85×85 mm FOV (0.120 mm ³)	0.98	0.88	0.89	0.98	0.12

FOV, field of view.

Accuitomo 170 is manufactured by J Morita Mfg. Corp., Kyoto, Japan; Kodak 9000 by Eastman Kodak Co., Rochester, NY; and Vatech Pax-Duo3D by Vatech, Seoul, Republic of Korea.

previous studies proved the superiority of CBCT over MDCT¹¹ and intraoral radiography.¹² CBCT may be a good adjunct to intraoral imaging in dentoalveolar trauma cases because the clinical diagnostic capacity of intraoral radiography is influenced by a number of variables, including beam angulation, exposure time, receptor sensitivity, processing, viewing conditions, superimposition of anatomic structures and lesion location.

We found that CBCT is very efficient in detecting and localizing HRF *ex vivo*. Strong observer reliability, extremely high Az values along with very high sensitivity, specificity and predictive values make high-resolution limited CBCT a very good candidate for diagnosing

HRF. Patient motion, which is an important source of artefacts in CBCT imaging, was not an issue for the present *ex vivo* research. This probably increased observer performance in the present study. In addition, CBCT has the potential to be the preferred modality in the clinical follow-up of patients with horizontally fractured teeth in terms of diagnosing resorption and periapical pathology and the healing process.¹⁴

Radiographic detection of HRF with CBCT is easier than that of vertical root fracture (VRF), which is mainly seen in teeth with root canal treatment, posts and pins. It should be noted that artefacts caused by root canal fillings, pins and posts may complicate the assessment of VRF. Beam hardening and cupping effect

is not an issue for most teeth with HRF in contrast to VRF. This may explain the reason why we found higher HRF detection accuracy compared with that of previous similar *ex vivo* studies assessing CBCT accuracy in the detection of VRF.¹⁵ However, our results are similar to a previous study, which found sensitivity 0.92 and specificity 0.97 for detection of HRF with CBCT.⁷ Considering the inclination of fracture line, we suggest assessing and scrolling through the coronal and cross-sectional images for HRF detection. On the other hand, for VRF detection, focussing on the axial images would be beneficial for better visibility.

The higher effective doses of CBCT when compared with conventional 2D imaging techniques is a matter of concern, and therefore CBCT should be used only if 2D techniques have been unsuccessful. However, current CBCT systems, like the ones chosen for this study, that offer limited FOV and lower doses may be considered safe tools for use in HRF detection, especially in suspected HRF cases where no information can be obtained by intraoral radiography. Effective doses with Accuitomo 170 were 43 μ Sv and 50 μ Sv with the smallest FOV and with a 100 $\times$ 50 mm FOV, respectively. For the Kodak 9000 system with a 50 $\times$ 37 mm FOV, effective

doses ranged between 19 μ Sv and 40 μ Sv.¹⁶ According to information provided from the company, effective doses with Vatech Pax-Duo3D was 42.52 μ Sv with a 50 $\times$ 50 mm FOV and 120.69 μ Sv with a 120 $\times$ 85 mm FOV. In addition, with most CBCT systems effective doses are lower in the anterior region compared with the posterior.¹⁶

Conclusion

CBCT units used at limited FOV and high resolution performed similarly in detecting simulated HRF *ex vivo*. Considering the lower dose advantage, limited CBCT units can be used with the smallest FOV for the detection of suspected HRF.

Acknowledgments

Authors are grateful to Dr Kemal Unsal of Digipano Dentomaxillofacial Imaging Center and to Dr Orhan Gulen of Dentistomo Dentomaxillofacial Imaging Center, Ankara, Turkey, for their invaluable support for the present study.

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