Dental Traumatology

Dental Traumatology 2009; **25**: 571–577; doi: 10.1111/j.1600-9657.2009.00833.x

Comparison of intraoral radiography and limited cone beam computed tomography for the assessment of root-fractured permanent teeth

Michael M. Bornstein[1], Andrea B. Wölner-Hanssen[1], Pedram Sendi[2], Thomas von Arx[1]

[1]Department of Oral Surgery and Stomatology, School of Dental Medicine, University of Bern, Bern, Switzerland; [2]Institute for Clinical Epidemiology & Biostatistics, Basel University Hospital, Basel, Switzerland

Correspondence to: Dr Michael M. Bornstein, Department of Oral Surgery and Stomatology, School of Dental Medicine, University of Bern, Freiburgstrasse 7, 3010 Bern, Switzerland
Tel.: +41 31 632 2545/66
Fax: +41 31 632 2503
e-mail: michael.bornstein@zmk.unibe.ch

Accepted 7 August, 2009

Abstract – *Aim*: To compare intraoral occlusal (OC) and periapical (PA) radiographs vs. limited cone beam computed tomography (CBCT) in diagnosing root-fractured permanent teeth. *Material and methods*: In 38 patients (mean age 24 years, range 8–52 years) with 44 permanent teeth with horizontal root fractures, intraoral radiographs (PA and OC) and limited CBCT were used to evaluate the location (apical, middle, cervical third of the root) and angulation of the fracture line. Furthermore, the conventional radiographs and CBCT images were compared for concordance of fracture location. *Results*: In the PA and OC radiographs, 28 fractures (63.6%) were located in the middle third of the root, 11 (25.0%) in the apical third and 5 (11.4%) in the cervical third. The PA/OC radiographs and the sagittal CBCT images (facial aspect) yielded the same level of root fracture in 70.5% of cases (31 teeth; 95% CI: 54.1–82.7%). The PA/OC radiographs and sagittal CBCT images (palatal aspect) showed the same level of root fracture in 31.8% of cases. There was a statistically significant association between the angle at which the root fracture line intersected the axis of the tooth and the level of root fracture in the facial aspect of the sagittal CBCT images. *Conclusions*: The diagnosis of the location and angulation of root fractures based on limited CBCT imaging differs significantly from diagnostic procedures based on intraoral radiographs (PA/OC) alone. The clinical significance for treatment strategies and for the prognosis of root-fractured teeth has to be addressed in future studies.

Root fractures of permanent teeth are caused by an impact with great force. Compression zones are created labially and/or lingually and the root is separated into a coronal and an apical fragment (1). Most often, root fractures occur in maxillary central (68%) and lateral (27%) incisors. The mandibular incisors are rarely affected (5%) (2).

The classification of root fractures is usually based on the level of the fracture with regard to the length of the root (apical third, middle third, cervical third), and on the degree of dislocation of the coronal fragment. The prognosis of the affected tooth is influenced by several factors, such as age of the patient, stage of root formation (apical closure), degree of dislocation of the coronal fragment, mobility of the coronal fragment, and width of diastasis between the fragments (2). The majority of root fractures affect the middle third of the root (3). Fractures located in the cervical part are considered to have the poorest prognosis (4, 5).

The radiologic evaluation of root fractures is usually performed with periapical and occlusal radiographs (6). However, the introduction of cone beam computed tomography (CBCT) has created new diagnostic possibilities in dentistry. The conventional and two-dimensional radiographic evaluation can now be completed with a third dimension: the orofacial view. CBCT has already been established as a valuable imaging technique in many dentomaxillofacial applications, ranging from oral surgery to orthodontics (7–14). However, the benefits and limitations of CBCT in dental traumatology, in particular for root-fractured teeth, have not yet been clarified.

The objectives of the present study were to compare traditional two-dimensional intraoral (periapical and occlusal) radiographs to limited CBCT images with regard to (i) fracture location and (ii) angulation of the root fractures as measured on sagittal CBCT images.

Materials and methods

Patients

All patients presenting as emergencies with single or multiple horizontal root fractures of permanent teeth at the Department of Oral Surgery and Stomatology between 08/2004 and 05/2008 were included in the present study. The traumatized teeth were assessed with periapical (PA) and occlusal (OC) radiographs as well as with CBCT. Teeth with fractures that were only detected in CBCT images but not in conventional intraoral radiographs (PA, OC) were excluded. Therefore, 38 consecutive patients were enrolled in the present study. The patients comprised 26 males and 12 females, with a mean age of 24 years (range: 8–52 years). From these patients, a total of 45 root-fractured permanent teeth were used for further analysis. One root-fractured tooth was excluded from further evaluation, since the root fracture was only located in the facial part of the root. Thus, the final material included 44 permanent teeth (43 central maxillary incisors and one lateral maxillary incisor) in 38 patients.

Radiographic techniques

The CBCT images were obtained with a 3 DX Accuitomo XYZ Tomograph (Morita, Tokyo, Japan) with a voxel size of 0.125 mm. Operating parameters were set at 3.0 mA and 80 kV and exposure time was 17.5 s. For all CBCT images a limited field of view of 4 × 4 cm was selected. The data were reconstructed with slices at an interval of 0.5 mm, which were positioned parallel to the horizontal axis of the alveolar bone. The root-fractured tooth was placed in the center of the volume. The slices were reformatted to place the tooth in a vertical position in the coronal view.

The periapical and occlusal radiographs were taken with a dental X-ray machine (HDX; Dental Ez, Lancaster, PA, USA) operating at 70 kV and with an exposure time of 0.12 s. For the occlusal radiographs (OC), a 6 × 8 cm F Speed film (Kodak Insight dental film; Eastman Kodak Company, Rochester, NY, USA) was used. The central beam was positioned through the median-sagittal plane, corresponding to an angle of 70° in relation to the film. For the periapical radiographs, F Speed films (3 × 4 cm or 2 × 3 cm Kodak Insight films; Eastman Kodak Company, Rochester, NY, USA) were used, and the central beam was placed perpendicular to the long axis of the tooth (paralleling technique) with a film holder (Rinn XCP; Dentsply Friadent Schweiz AG, Nidau, Switzerland).

Evaluation of the images

The intraoral radiographs and the CBCT images were all evaluated by one experienced graduate student not directly involved in the treatment and follow-up of the patients included (A. W.-H.). The OC and PA radiographs were processed in an automatic processor (XR 24PRO; Dürr Dental, Bietigheim, Germany) and analyzed using a light box. CBCT images were analyzed using a Dell 380 Precision workstation (Dell SA, Geneva, Switzerland) and a 19-in. Eizo Flexscan monitor with a resolution of 1280 × 1024 pixels (Eizo Nanao AG, Wädenswil, Switzerland). The sagittal CBCT images were printed out with a magnification of 310% for further analysis.

For the relative level of the fracture line, the same classification was used for PA, OC and sagittal CBCT images (apical, middle, cervical third of the root). For the sagittal CBCT slices, the level of the root fracture was examined for the facial and palatal aspects of the root. The total length of the root was defined as the distance from the apex to the cemento-enamel junction. The length of the apical fragment was extrapolated from the total length of the root: If the fracture line (facial or palatal) was positioned at 0–33% of the total length, the relative fracture level was defined as apical; at 34–66% it was defined as middle, and at 67–100% it was defined as cervical (Fig. 1).

Periapical/intraoral occlusal images were compared to the sagittal view of CBCT concerning the level of root fracture. If the root fracture was not visible on the PA, the OC was used for comparison with the sagittal CBCT image. First, we evaluated whether the fracture level of PA/OC was on an equal level, i.e. 'facial *and* palatal', '*only* facial', '*only* palatal' or '*neither* facial *nor* palatal' compared to the CBCT. Then, the correlation of fracture levels in PA/OC with the *facial* aspect of CBCT or the *palatal* aspect of CBCT was evaluated.

In non-straight fracture lines, the entry and exit points of the fracture were connected for further evaluation. The facial and palatal angles between the fracture line and the long axis of the root were measured using a set square on the printout of the sagittal CBCT image (Fig. 2). The level of the root fracture line (apical, middle, cervical third of the root) was further related to the calculated angle of the fracture in order to evaluate a possible correlation between location and angle of the root fracture.

Statistics

The test of proportions involving a binomial distribution with Yates' continuity correction was used to assess whether the proportion of identical classification (identical classification = 1, no identical classification = 0) with respect to the level of the root fracture (i.e. apical, middle, cervical third of the root) in PA/OC radiographs and facial/palatal aspects of the CBCT images was statistically significantly different from 50% [i.e. PA/OC vs. $CBCT_{facial}$ ($CBCT_f$); PA/OC vs. $CBCT_{palatal}$ ($CBCT_p$); PA/OC vs. $CBCT_{facial/palatal}$ ($CBCT_{f/p}$)]. The null value of 50% was chosen to address the clinician's viewpoint that any agreement in film/CBCT greater than 50% was considered as clinically relevant. In addition, the 95% confidence intervals for the respective proportions were calculated.

The Kruskal–Wallis rank sum test was used to estimate whether the angle between the root fracture line and axis of the tooth was associated with the level of palatal and facial root fracture location in the sagittal CBCT images. The Wilcoxon rank sum test was thereafter used to identify between which groups the statistical significance would lie.

For all tests a P value ≤0.05 was considered as statistically significant. The statistical software package S-Plus Professional (Version 6.2; Insightful Software, Palo Alto, CA, USA) was used for all analyses.

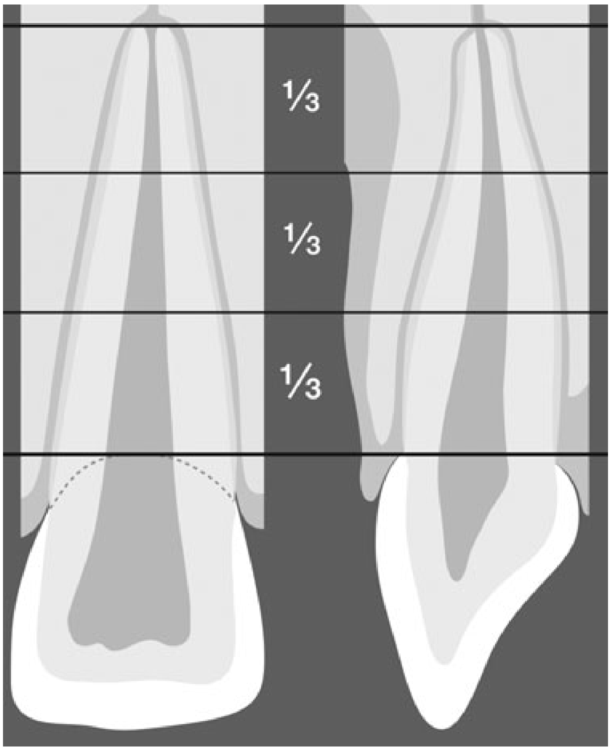

Fig. 1. Schematic illustration of the classification of the different root fracture levels (apical, middle, cervical third of the root).

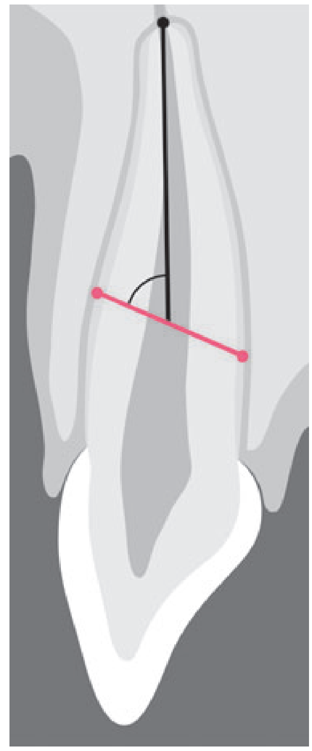

Fig. 2. Schematic illustration of the calculation of the angle between the fracture line and the long axis of the root.

Results

Of the 44 permanent teeth with root fractures included in the present study, six were visible on PA but not on OC, and one was detected on OC but not on PA (Fig. 3). In the occlusal and periapical radiographs, 28 fractures (63.6%) were located in the middle third of the root, 11 (25.0%) in the apical third and 5 (11.4%) in the cervical third (Table 1). In the sagittal CBCT images, the location of the fracture line was further differentiated to include the facial and the palatal aspects of the affected root. On the facial aspect, 31 teeth had fractures in the middle third of the root, 30 teeth had a fracture located in the cervical third on the palatal aspect of the root.

The evaluation of concordance of fracture location in PA/OC compared to CBCT ('facial *and* palatal', '*only* facial', '*only* palatal' or '*neither* facial *nor* palatal') showed the following results (Table 2): in 32 out of 44 teeth (72.7%), the level of the fracture line assessed on intraoral radiographs differed in one or more aspects from the level of the fracture line based on CBCT images alone. The highest correlation (5/5; 100%) was seen in cervical fractures in PA/OC with a corresponding cervical location in CBCT 'facial *and* palatal'. A high correlation (60.7%) was also found for fractures in the middle third of the root in PA/OC and the '*only* facial' aspect in CBCT. The lowest PA/OC-CBCT concordance was found for a root fracture location in the apical third: only one tooth out of 11 with an apical fracture location in PA/OC had a corresponding 'facial *and* palatal' location in CBCT.

Comparing fracture location in *facial* CBCT versus PA/OC and *palatal* CBCT versus PA/OC, the following results were seen (Table 3): 8/11 teeth (72.7%) classified as apical fractures in PA/OC were located in the middle third on the *facial* aspect using CBCT. On the *palatal* aspect 5/11 fractures (45.5%) were located in the middle third and 5/11 fractures (45.5%) in the cervical third. A high correlation (23/28; 82.1%) was found for middle fracture location in PA/OC and middle location in the CBCT on the *facial* aspect, whereas the correlation on the palatal aspect was low (8/28; 28.6%). The highest correlation (5/5; 100%) was found for cervical fracture location in PA/OC, with an identical fracture location on both the facial and palatal aspects of the CBCT.

The PA/OC radiographs and the facial CBCT images yielded the same level of root fracture in 70.5% of cases (31 teeth; 95% CI: 54.1–82.7%), which was statistically significantly different from (i.e. higher than) 50% ($P = 0.0104$). The PA/OC radiographs and palatal CBCT images exhibited the same level of root fracture in 31.8% of cases (14 teeth; 95% CI: 15.4–43.0%), which was statistically significantly different from (i.e. smaller than) 50% ($P = 0.0237$). All three imaging measurements (i.e. PA/OC, $CBCT_{facial}$ and $CBCT_{palatal}$) yielded the same results in only 27.2% of cases (95% CI: 15.4–43.0%), which was statistically significantly different from 50% ($P = 0.0042$).

The calculated mean angle between the fracture line and the long axis of the root on the facial aspect was 60.1° (range: 27–94°). The greatest mean angle (75.9°) was found for fractures located in the cervical third

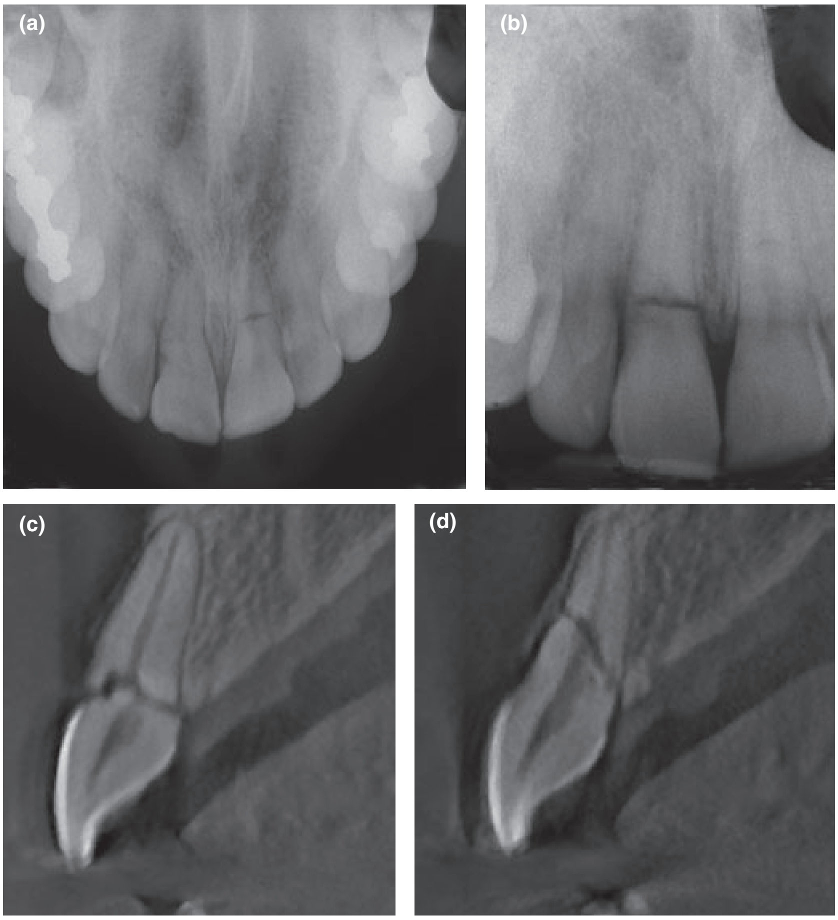

Fig. 3. (a) In a 36-year-old patient, a root fracture can be seen in the middle third of the left central maxillary incisor on the occlusal radiograph. (b) On the periapical radiograph of the same patient, a root fracture is visible in the cervical third of the right central maxillary incisor. (c) The sagittal cone beam computed tomography (CBCT) slice shows the cervical location of the root fracture in the right central maxillary incisor (cervical third on facial and palatal aspects). (d) Also the left central maxillary incisor shows a root fracture on the sagittal CBCT slice (middle third on facial aspect, and cervical third on palatal aspect).

Table 1. Location of the root fractures using PA/OC radiographs and sagittal slices of limited CBCT imaging ($n = 44$)

	Fracture location with PA/OC	Fracture location on sagittal CBCT images	
		Facial	Palatal
Apical third	11 (25.0%)	4 (9.1%)	1 (2.27%)
Middle third	28 (63.64%)	31 (70.45%)	13 (29.55%)
Cervical third	5 (11.36%)	9 (20.45%)	30 (68.18%)

PA, periapical; OC, occlusal, CBCT; cone beam computed tomography.

(Table 4). With regard to the correlation between the calculated angle of the fracture and its level, the following observations were made: for PA/OC radiographs, a fracture with an angle ≤60° was never located in the cervical third of the root. On the facial aspect of CBCT images, all fractures ≤50° were found in the middle third of the root (Table 5). On the palatal aspect of CBCT views, the majority of fractures were located in the cervical third of the root, irrespective of the size of the fracture angle. There was a statistically significant association between the angle at which the root fracture line intersected the axis of the tooth and the level of root fracture in the facial CBCT images ($P = 0.0045$). Fractures located in the cervical third exhibited a greater angle (mean: 76; median: 79) than fractures in the middle third of the roots (mean: 55; median: 53; $P = 0.0015$). For fractures on the palatal images of the roots, the results were not statistically significant.

Table 2. Concordance of fracture location between PA/OC images and CBCT ($n = 44$)

	Facial and palatal concordance with CBCT	Only facial concordance with CBCT	Only palatal concordance with CBCT	No concordance with CBCT
Middle fracture location with PA/OC (n = 28)	6 (21.4%)	17 (60.7%)	2 (7.2%)	3 (10.7%)
Cervical fracture location with PA/OC (n = 5)	5 (100%)	–	–	–
Subtotal	–	19 (43.2%)	2 (4.5%)	11 (25.0%)
Total (n = 44)	12 (27.3%)	32 (72.7%)		

PA, periapical; OC, occlusal; CBCT, cone beam computed tomography.

Table 3. Location of the root fracture level on the facial and palatal aspects of the sagittal CBCT images in comparison to PA/OC radiographs ($n = 44$)

	PA/OC apical third	PA/OC middle third	PA/OC cervical third	Total teeth
CBCT				
facial aspect				
apical third	**3[1] (27.3%)**	1 (3.6%)	0 (0%)	4 (9.0%)
middle third	8 (72.7%)	**23[1] (82.1%)**	0 (0%)	31 (70.5%)
cervical third	0 (0%)	4 (14.3%)	**5[1] (100%)**	9 (20.5%)
CBCT				
palatal aspect				
apical third	**1[1] (9.0%)**	0 (0%)	0 (0%)	1 (2.3%)
middle third	5 (45.5%)	**8[1] (28.6%)**	0 (0%)	13 (29.5%)
cervical third	5 (45.5%)	20 (71.4%)	**5[1] (100%)**	30 (68.2%)
Total	11	28	5	44

PA, periapical; OC, occlusal; CBCT, cone beam computed tomography.
[1]*n* and percentages in bold indicate similar fracture levels with PA and CBCT.

Table 4. Calculated facial angles between the fracture line and the long axis of the root as calculated on the sagittal CBCT image ($n = 44$)

	Mean (°)	Minimum (°)	Maximum (°)
Apical[1] third (n = 4)	63.4 (±15.5)	52.5	90
Middle[1] third (n = 31)	55 (±14.6)	27	90
Cervical[1] third (n = 9)	75.9 (±12.9)	57	94
All (n = 44)	60.1 (±16.6)	27	94

[1]Fracture location determined on facial aspect in sagittal CBCT view.
CBCT, cone beam computed tomography.

Discussion

The present study evaluated and compared the findings of root-fractured teeth using PA/OC radiographs and limited CBCT images. The PA/OC radiographs and the facial aspect of CBCT images yielded the same level of root fracture in 70.5% of cases, whereas PA/OC radiographs and palatal CBCT images yielded the same level of root fracture in 31.8% of cases. All three imaging measurements (PA/OC, $CBCT_{facial}$ and $CBCT_{palatal}$) yielded the same results in only 27.2% of cases.

Root fractures are a rather uncommon finding, accounting for 0.5–7% of dental injuries that occur in the permanent dentition (15). Clinically, root fractures may present as a slightly extruded tooth, frequently displaced towards the palate, and affected teeth are often mobile (16). Complete clinical and radiographic examinations combined with a correct diagnosis of the dental pulp status are fundamental to ensure proper treatment and good prognosis of the root-fractured tooth (17, 18). The International Association of Dental Traumatology (IADT) recently published guidelines for the management of traumatic dental injuries recommending at least three intraoral radiographs as a routine radiographic examination for fractures and luxations of permanent teeth (19): (i) a radiograph at a 90° horizontal angle with the central beam through the tooth in question, (ii) an occlusal view, and (iii) a lateral view from a mesial or distal aspect of the affected tooth.

Nevertheless, a radiographic examination based on traditional two-dimensional plain-film projection has several limitations, an important one being that the radiation beam must pass through the fracture line to visualize it (20). Often, root fractures are not even diagnosed in routine daily practice, as reported by a recent study, where expert examiners found an additional 21 occult fractures that were not detected by the treating dentist at the time of injury (21). Also in the present study, the difficulty of visualizing horizontal root fractures with two-dimensional radiography and the need for multiple intraoral images is demonstrated by the fact that of the 44 root-fractured teeth included, six fractures were visible on PA radiographs but not on OC images, and one was detected with OC but not PA radiographs.

Numerous efforts have been made of three-dimensional radiographic imaging in all fields of dentistry, ranging from oral surgery to orthodontics. Although computerized tomography (CT) has been available for quite some time, its use in dentistry has always been limited because of cost, access, and radiation (22). The introduction of cone-beam computed tomography (CBCT) represented an important new development in dento-maxillofacial radiology, and precipitated a shift from two- to three-dimensional data acquisition, image reconstruction, and visualization.

Especially for the diagnosis of endodontic pathology, CBCT has demonstrated important advantages over conventional intraoral radiographs. Lofthag-Hansen et al. (13) compared PA radiographs and limited CBCT for detection of apical pathology in maxillary molars and premolars and in mandibular molars. The study demonstrated that 38% of the lesions were undetected by PA radiography, despite the fact that an additional PA radiograph was taken from a different angle. These findings were confirmed in a recent study by Low et al.

Table 5. Correlation between calculated angle (facial and palatal) and root fracture level ($n = 44$)

	PA/OC			CBCT (facial aspect)			CBCT (palatal aspect)		
Angle	A	M	C	A	M	C	A	M	C
≤50° n = 11	4	7	0	0	11	0	0	1	10
>50° and ≤60° n = 17	5	12	0	3	12	2	0	7	10
>60° n = 16	2	9	5	1	8	7	1	5	10
Total	11	28	5	4	31	9	1	13	30

PA, periapical; OC, occlusal; CBCT, cone beam computed tomography.

(14), in which 34% of roots with periapical lesions were only detected on CBCT images. Standard intraoral imaging techniques have limitations in their sensitivity and specificity when assessing pathologies of teeth, as has been demonstrated by a recent study evaluating different imaging methods (CBCT, panoramic and periapical radiographs) concerning the predictive values and accuracy of the detection of apical periodontitis (23). Apical periodontitis was correctly identified with panoramic and periapical radiographs, but only when the lesion was in an advanced stage. The prevalence of apical periodontitis was significantly higher with CBCT, since apical periodontitis was detected at an earlier stage.

The potential use of CBCT for the diagnosis of dental trauma has been reported only in a limited number of publications, i.e. a review paper (24), two *in vitro* studies (25, 26), a case report (27), and one case series study (28). In the recent case series study from Brazil, 20 patients with endodontically treated teeth were analyzed for root fractures using PA radiographs and CBCT (28). The results demonstrated statistically significantly less precise detection of root fractures for two-dimensional radiographs compared to CBCT. For two cases, the fracture was also not detected using three-dimensional imaging, probably due to metallic artifacts from the root canal filling material or posts. In the present study, a root fracture could be clearly detected in all 44 included cases using CBCT images, probably because the patients were generally younger (mean age of 24 years), and the teeth affected were not endodontically treated, thus averting potential diagnostic problems due to artifacts.

The present study demonstrated that the use of CBCT for the diagnosis of root fractures resulted in significantly different findings than the use of conventional PA/OC radiography alone. Similar findings were also reported for comparative studies regarding CBCT imaging vs. conventional radiography for the diagnosis of periapical pathology (13, 14, 23), and confirm initial reports addressing root fractures (24–28). With regard to the location of the root fracture, the radiographic techniques analyzed (i.e. PA/OC radiographs and $CBCT_{f/p}$) showed an identical fracture location in only 27.3% of cases. The sagittal CBCT planes showed that the fracture level was most often located in the middle third on the facial aspect (31 teeth/70.5%) and in the cervical third on the palatal aspect (30 teeth/68.2%). As a consequence, a facial location of the fracture in the middle or apical third was often associated with a cervical fracture location on the palatal aspect of the root (oblique course of the fracture in the oro-facial plane).

The results from the present study may be important for the treatment of root-fractured teeth and thus for establishing a prognosis. The fact that most fractures are described in the literature as being located in the middle third of the root should be reconsidered (4, 5), especially given that this diagnosis was based primarily on two-dimensional intraoral radiographs. Furthermore, in the present study 30 teeth (68.2%) had a fracture located in the cervical third on the palatal aspect of the root. It is known from the literature that horizontal root fractures in the cervical part of the root have the poorest prognosis of intra-alveolar root fractures (4, 5, 29, 30). In a recent study assessing the survival of 534 root-fractured teeth (5), 77 teeth with horizontal fractures at the cervical part of the root were extracted during the course of the study. This accounted for about 70% of the teeth included in that group. Future studies including CBCT imaging for treatment planning are needed to verify the high incidence of cervical root fractures found in the present study, and also to correlate these three-dimensional findings to the long-term prognosis of the affected teeth.

Regarding the findings in the present study, limited CBCT seems to have the potential to replace conventional radiographs for accurate diagnosis of teeth after dento-alveolar trauma. Also in comparison to computed tomography (CT), CBCT has clear advantages, the most important being less radiation administered to the patient (24). Imaging with the NewTom QR-DVT 9000 resulted in an effective absorbed dose ranging from 19.9–77.9 μSv (31), compared to a range of 6.2–22 μSv for panoramic views, and 314 μSv for conventional CT scans. In a recent study evaluating the effective dose for the CBCT device used in the present study (32), 20.02 μSv were measured for a limited field of view (FOV) of 4×4 cm, whereas 43.27 μSv were detected for a larger FOV (6×6 cm). Therefore, a smaller FOV should always be used when possible, thus adhering to the ALARA (as low as reasonably achievable) principle (33).

In conclusion, limited CBCT imaging offers the clear advantage over conventional imaging (PA and OC) that traumatized teeth can be visualized in all three dimensions – especially the oro-facial dimension. An interesting finding is the high percentage (almost 70%) of root fractures located in the cervical part in the facial aspect of the tooth. The clinical significance for treatment strategies and also for the prognosis of the traumatized teeth has to be addressed in future studies.

Acknowledgments

The authors would like to thank Ueli Iff, Medical Illustrator, School of Dental Medicine, University of Bern, for providing the schematic illustrations.

Conflict of interest

There are no financial relations between any author and a commercial company that may pose a conflict of interest.

References

1. Welbury RR, Kinirons MJ, Day P, Humphreys K, Gregg TA. Outcomes for root-fractured permanent incisors: a retrospective study. Pediatr Dent 2002;24:98–102.
2. Caliskan MK, Pehlivan Y. Prognosis of root-fractured permanent incisors. Endod Dent Traumatol 1996;12:129–36.
3. Andreasen FM, Andreasen JO, Bayer T. Prognosis of root-fractured permanent incisors—prediction of healing modalities. Endod Dent Traumatol 1989;5:11–22.
4. Cvek M, Andreasen JO, Borum MK. Healing of 208 intraalveolar root-fractures in patients aged 7–17 years. Dent Traumatol 2001;17:53–62.
5. Cvek M, Tsilingaridis G, Andreasen JO. Survival of 534 incisors after intra-alveolar root fracture in patients aged 7–17 years. Dent Traumatol 2008;24:379–87.

6. von Arx T, Winzap-Kälin C, Hänni S. Injuries to permanent teeth. Part 1. diagnosis of the tooth injury (in German). Schweiz Monatsschr Zahnmed 2005;115:133–9.
7. Heiland M, Schulze D, Rother U. Postoperative imaging of zygomaticomaxillary complex fractures using digital volume tomography. J Oral Maxillofac Surg 2004;62:1387–91.
8. Pohlenz P, Blessmann M, Blake F, Heinrich S, Schmelzle R, Heiland M. Clinical indications and perspectives for intraoperative cone beam computed tomography in oral and maxillofacial surgery. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103:412–7.
9. Angelopoulos C, Thomas SL, Hechler S, Parissis N, Hlavacek M. Comparison between digital panoramic radiography and cone-beam computed tomography for the identification of the mandibular canal as part of presurgical dental implant assessment. J Oral Maxillofac Surg 2008;66:2130–5.
10. Pawelzik J, Cohen M. A comparison of conventional panoramic radiographs with volumetric computed tomography images in the preoperative assessment of impacted mandibular third molars. J Oral Maxillofac Surg 2002;60:977–8.
11. Aboudara CA, Hatcher D, Nielsen IL, Miller A. A three-dimensional evaluation of the upper airway in adolescents. Orthod Craniofac Res 2003;6(Suppl 1):173–5.
12. Young GR. Contemporary management of lateral root perforation diagnosed with the aid of dental computed tomography. Aust Endod J 2007;33:112–8.
13. Lofthag-Hansen S, Huumonen S, Gröndahl K, Gröndahl HG. Limited cone-beam CT and intraoral radiography for the diagnosis of periapical pathology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103:114–9.
14. Low K, Dula K, Bürgin W, von Arx T. Comparison of periapical radiography and limited cone-beam tomography in posterior maxillary teeth referred for apical surgery. J Endod 2008;34:557–62.
15. Çaliskan MK, Pehelivan Y. Prognosis of root-fractures permanent incisors. Endod Dent Traumatol 1996;12:129–36.
16. von Arx T, Chappuis V, Hänni S. Injuries to permanent teeth. Part 3: Therapy of root fractures (in German). Schweiz Monatsschr Zahnmed 2007;117:134–48.
17. Majorana A, Pasini S, Bardellini E, Keller E. Clinical and epidemiological study of traumatic root fractures. Dent Traumatol 2002;18:77–80.
18. Versiani MA, Alves de Sousa CJ, Cruz-Filho AM, da Cruz Perez DE, Sousa-Neto MD. Clinical management and subsequent healing of teeth with horizontal root fractures. Case report. Dent Traumatol 2008;24:134–9.
19. Flores MT, Andersson L, Andreasen JO, Bakland LK, Malmgren B, Barnett F et al. Guidelines for the management of traumatic dental injuries. I. Fractures and luxations of permanent teeth. Dent Traumatol 2007;23:66–71.
20. Kositbowornchai S, Sikram S, Nuansakul R, Thinkhamrop B. Root fracture detection on digital images: effect of the zoom function. Dent Traumatol 2003;19:154–9.
21. Molina JR, Vann WF Jr, McIntyre JD, Trope M, Lee JY. Root fractures in children and adolescents: diagnostic considerations. Dent Traumatol 2008;24:503–9.
22. White SC, Pharoah MJ. The evolution and application of dental maxillofacial imaging modalities. Dent Clin North Am 2008;52:689–705.
23. Estrela C, Bueno MR, Leles CR, Azevedo B, Azevedo JR. Accuracy of cone beam computed tomography and panoramic and periapical radiography for detection of apical periodontitis. J Endod 2008;34:273–9.
24. Cohenca N, Simon JH, Roges R, Morag Y, Malfaz JM. Clinical indications for digital imaging in dento-alveolar trauma. Part 1. Traumatic injuries. Dent Traumatol 2007;23: 95–104.
25. Mora MA, Mol A, Tyndall DA, Rivera EM. In vitro assessment of local computed tomography for the detection of longitudinal tooth fractures. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103:825–9.
26. Mora MA, Mol A, Tyndall DA, Rivera EM. Effect of the number of basis images on the detection of longitudinal tooth fractures using local computed tomography. Dentomaxillofac Radiol 2007;36:382–6.
27. Ilgüy D, Ilgüy M, Fisekcioglu E, Bayirli G. Detection of jaw and root fractures using cone beam computed tomography: a case report. Dentomaxillofac Radiol 2009;38:169–73.
28. Bernardes RA, de Moraes IG, Duarte MA, Azevedo BC, de Azevedo JR, Bramante CM. Use of cone-beam volumetric tomography in the diagnosis of root fractures. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:270–7.
29. Cvek M, Mejàre I, Andreasen JO. Healing and prognosis of teeth with intra-alveolar fractures involving the cervical part of the root. Dent Traumatol 2002;18:57–65.
30. Welbury R, Kinirons MJ, Day P, Humphreys K, Gregg TA. Outcomes for root-fractured permanent incisors: a retrospective study. Pediatr Dent 2002;24:98–102.
31. Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit. Dentomaxillofac Radiol 2003;32:229–34.
32. Hirsch E, Wolf U, Heinicke F, Silva MA. Dosimetry of the cone beam computed tomography Veraviewepocs 3D compared with the 3D Accuitomo in different fields of view. Dentomaxillofac Radiol 2008;37:268–73.
33. McCollough CH, Primak AN, Braun N, Kofler J, Yu L, Christner J. Strategies for reducing radiation dose in CT. Radiol Clin North Am 2009;47:27–40.