Diagnostic value of cone beam computed tomography for recognition of oblique root fractures: An in vitro study

Wartość diagnostyczna tomografii komputerowej wiązki stożkowej w rozpoznawaniu skośnych złamań korzeni zębów – badania in vitro

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Abstract

Background. Diagnosis of tooth root fractures is based on radiographic examination, which is not reliable in the case of oblique root fractures.

Objectives. The aim of the study was to evaluate the efficacy of cone beam computed tomography (CBCT) imaging of oblique root fractures.

Material and methods. Twenty-four bovine incisors were used in the study. They were randomly divided into 2 groups: an experimental group with artificially created oblique root fractures and a control group without fractures. The teeth underwent a CBCT evaluation with a CS 9300 cone-beam scanner (Carestream, Rochester, USA) using a 5×5 cm field of view with the resolution up to 90 μ m, and a dental radiography. The specimens were examined by 2 observers with different job experience.

Results. In the CBCT scans, fracture lines were detected in 95.8% of cases (the 1st observer made a proper diagnosis in 100% of cases and the 2nd in 91.7%). Fracture lines were identified on radiographs in 33.3% of roots (the 1st observer was able to see the lines in 41.7% of cases and the 2nd in 25%). The inter-observer agreement was very high (the kappa coefficient for CBCT scans was 1.00 and 0.88 for radiographs). The best diagnostic value was recorded for contiguous slices.

Conclusions. Cone beam computed tomography with a small field of view and high resolution significantly surpasses radiographs in effective imaging of oblique tooth root fractures and should be the method of choice in the diagnosis of these fractures.

Key words: cone beam computed tomography, dental root fracture, diagnosis

Słowa kluczowe: tomografia komputerowa wiązki stożkowej, skośne złamanie korzenia, diagnostyka

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In recent years, tooth trauma has been frequently a cause of patients reporting to the dental office.¹ Traumatic injuries to anterior teeth usually result in horizontal or oblique tooth root fractures.^{2,3} Jayasudha et al. evaluated different dynamic forces acting on the tooth during the injury using a three dimensional (3D) experimental model.⁴ Researchers stated that the greatest stresses in the dental and the alveolar bone tissues are induced by horizontal forces, leading to oblique fractures in the cervical or radicular region of the tooth. Another cause of oblique root fractures is repeated excessive pressure during the mastication of hard food,^{5,6} which is usually observed in subjects above the age of 40 years and mostly affects lateral teeth, resulting from age-related changes in tooth elasticity and the presence of numerous and large fillings.⁷

There is a lack of data on the prevalence of oblique root fractures, because they are frequently recognized as horizontal ones. The diagnosis of tooth root fractures is predominantly based on radiological imaging, which is often unreliable in relation to oblique fractures. The central ray of the X-ray beam, despite taking images at different angles (3 or more projections), does not always pass through the fracture fissure running obliquely to the long axis of the tooth. In addition, the fracture, which is recognized in the cervical third of the root on an X-ray taken with the use of the right angle technique, is visible at a different height on an occlusal or oblique radiograph.⁸

Improper recognition of the course of the fracture fissure is a cause of frequent therapeutic failures. Therefore, the study on the diagnostic possibilities of CBCT in identifying oblique root fractures is justifiable.

The aim of the study was to evaluate the efficacy of imaging oblique root fractures of teeth by using cone beam computed tomography (CBCT).

Material and methods

Twenty-four bovine lateral incisors of the mandible (the animals aged up to 36 months) were obtained from a slaughterhouse. After extraction, the teeth were cleansed from periodontal tissues and stored in 0.5% thymol solution at room temperature for maximally 2 months. The teeth were assessed under a microscope in order to eliminate roots with cracks. The pulp was extirpated according to the guidelines of the International Organization for Standardization.⁹

After cutting off the crowns below the cemento-enamel junction, the roots were randomly divided into 2 groups, experimental (A) and control (B). In group A, an oblique fracture was generated in each root by using a universal testing machine Zwick/Roell Z020 (Zwick GmbH & Co. KG, Ulm, Germany), with 3-point flexure (Fig. 1). Two parts of each tooth were pieced together and tightly glued with a universal scotch gel. In this way, the fracture fis-

Fig. 1. Generating oblique fractures by using a universal testing machine Zwick/Roell Z020

sure width less than 0.1 mm was obtained in all fractures. The fissure width was evaluated with an electronic caliper (TESA Caliper IP67, 150 mm; TESA Technology, Renens, Switzerland) whose measurement accuracy was 0.01 mm, confirmed by the calibration certificate No. AP302.1/12. The certificate was issued by the Mikro Pomiar calibration laboratory accredited by the Polish Centre for Accreditation. The measurements were performed centrally to the long axis of the tooth in relation to 2 constant reference points. Group B (control) consisted of the roots without fractures. The investigations were carried out in the University Laboratory of Material Research of the Medical University of Lodz (Poland). The teeth of both groups underwent radiographic and CBCT examination.

Positioning of samples

The roots of the studied teeth were covered with a layer of wax to simulate the periodontal ligament space. Next, they were placed in the alveoli of the human mandible and tightly adhered to the alveolar walls (Fig. 2). The vestibular and lingual aspects of the mandibular body were covered with 3 layers of modelling wax, each one 1.6 mm thick, which simulated soft tissues.

Fig. 2. A study model – human mandible with the dental root placed in the alveolus

Volumetric scanning

The samples were scanned with computed tomography CS 9300 Carestream® (Carestream, Rochester, USA) and a variable field of view. The mandible was placed in the center of the CT scan range, according to the X, Y, Z lines, which ensured repeatability of visualization conditions. The universal field of view (5×5 cm) with the $90 \mu\text{m}$ resolution was used in the study. Volumetric data was saved in the DICOM 3 format, and the images were analyzed using a compatible CS 3D Imaging Software (Carestream). The assessment was performed in axial, sagittal, frontal, transsectional and contiguous slices. Translucency was considered to be the fracture fissure when its borders did not exceed the outline of the tooth and were visible at least on 2 consecutive slices.¹⁰

Radiographs

Digital radiographs of both groups were taken with the Kodak 2200 Intraoral X-ray System + Kodak RVG 5100 Digital Radiography System (Carestream), which operates at a fixed distance of 25 cm between the radiation source and a detector. The CCD sensor was placed in the X-ray image positioner, which enabled the researchers to maintain exposure reproducibility (Fig. 3). The images were analyzed using the compatible Kodak Dental Imaging System Software. Translucency was considered to be a fracture fissure when its borders did not exceed the outline of the tooth.

Fig. 3. Kodak 2200 Intraoral X-ray System with study model and the CCD sensor placed in the X-ray image positioner

Evaluation of radiographs

X-rays and CBCT scans were evaluated according to the 2-grade scale where: – was invisible fracture and + was visible fracture.

The evaluation was performed by 2 observers who differed in the time of professional work experience (observer I had been working as a dentist for 5 years and observer II for 30 years). They used a 19-inch LCD monitor (NEC MultiSync EA192M, USA; resolution 1280×1024). The time of evaluation was not limited. The inter-observer agreement was expressed by means of the kappa coefficient,¹¹ in which the value <0.10 shows a lack of agreement; $0.11–0.20$ a very low level of agreement; $0.21–0.40$ low; $0.41–0.60$ moderate; $0.61–0.80$ high; and $0.81–1.00$ a very high level of agreement.

In the statistical analysis of the study results, the χ^2 test of independence and the Fisher's exact test (depending on the expected cell counts in the contingency tables) were used to compare the frequency of visualization of fracture fissures.¹² The following measures were used to evaluate the research methods: sensitivity, specificity, and accuracy. Sensitivity describes which percentage of fractured teeth is detected by means of a given method, specificity shows which percentage of teeth without fractures is properly diagnosed, and accuracy presents the probability of a correct diagnosis using a given method (the extent to which a researcher can be certain that the obtained result is true).

The level of significance for the applied tests was set at $\alpha = 0.05$. The statistical analysis was performed using STATISTICA v. 12 PL (StatSoft, Tulsa, USA).

The similar above-mentioned methodology was used in the author's previous publications.^{13–15}

Results

Table 1 presents a comparison of the prevalence of fracture fissure identification by means of CBCT and radiographs in the teeth with and without fracture (control group) (Fig. 4, 5). The 1st observer established the correct diagnosis in all evaluated cases in the CBCT study, while the 2nd one in 91.7%. Fracture fissures in the teeth with generated oblique fractures were visible in 95.8% of the CBCT scans. Both observers correctly recognized the fracture fissure in 33.3% of the dental roots on the radiographs; the 1st researcher found fractures in 41.7% of the cases and the 2nd one in 25%. In the control group (B), both observers made the correct diagnoses in all examined cases, both in CBCT and radiographic examinations.

Table 1. Frequency of fracture fissure detection for CBCT scans and radiographs in the teeth with oblique fractures and in controls

Group	CBCT – correct diagnoses, n (%)	RTG – correct diagnoses, n (%)	p-value
A – oblique fractures (observer I)	12 (100)	5 (41.7)	0.016
A – oblique fractures (observer II)	11 (91.7)	3 (25)	0.008
A – total	23 (95.8)	8 (33.3)	0
B – control	12 (100)	12 (100)	1

CBCT – cone beam computed tomography.

As can be seen from the data in Table 1, the frequency of correct detection of oblique tooth root fractures for the CBCT scans was statistically significantly higher than for the radiographs ($p < 0.05$). This correlation denoted the presence of statistically significant differences in the sensitivity, specificity and accuracy used to describe the evaluated radiological methods in further analysis (Table 2). These differences can occur in all parameters or only in some of them.

The sensitivity, as described above, was 95.8% for CBCT scans and 33.3% for radiographs. The specificity reached the same 100% value in both diagnostic methods. The diagnostic accuracy for radiographs (66.7%) was lower than in the CBCT evaluation (97.9%) (Table 2).

Table 3 presents the diagnostic value of particular CBCT slices in the detection of the oblique root fractures. The data shows that the best diagnostic value was obtained for the contiguous slices.

The evaluation of the inter-observer agreement expressed by the kappa coefficient for the CBCT and radiographic evaluation is presented in Table 4. The kappa coefficient for the teeth with oblique fractures was 0.70 in the X-ray examination and 0.92 in relation to CBCT scans. The inter-observer agreement was, therefore, very high for the volumetric tomography studies and high for radiographs (Table 4).

Fig. 4A. X-ray of tooth No. 2 – fracture not visible

Fig. 4B. Contiguous slice of tooth No. 2 – fracture visible

Fig. 4C. Transsectional slice of tooth No. 2 – fracture visible

Fig. 5A. X-ray of tooth No. 12 – fracture visible

Fig. 5B. Sagittal slice of tooth No. 12 – fracture visible

Fig. 5C. Transsectional slice of tooth No. 12 – fracture visible

Table 2. Sensitivity, specificity and accuracy for CBCT scans and radiographs in the detection of oblique root fractures according to the observer

Test	Total CBCT scans	CBCT 1	CBCT 2	Total radiographs	RTG 1	RTG 2
Sensitivity	95.80%	100.00%	91.70%	33.30%	41.70%	25.00%
Specificity	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Accuracy	97.90%	100.00%	95.80%	66.70%	70.80%	62.50%

CBCT – cone beam computed tomography.

Table 3. Diagnostic value of particular CBCT slices in the detection of oblique root fractures

Test	CBCT – total	Axial	Frontal	Sagittal	Transsectional	Contiguous
Sensitivity	95.80%	83.30%	91.70%	95.80%	91.70%	100.00%
Specificity	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Accuracy	97.90%	91.70%	95.80%	97.90%	95.80%	100.00%

CBCT – cone beam computed tomography.

Table 4. The inter-observer agreement for the CBCT and radiographic study in the detection of oblique root fractures

Method	Sample	Kappa coefficient	Error	Test statistics	p-value
CBCT	oblique	0.92	0.08	4.51	0
Radiographs	oblique	0.7	0.19	3.61	0

CBCT – cone beam computed tomography.

Discussion

The subject of diagnosing oblique dental root fractures has been rarely undertaken in literature and concerned monitoring of post-traumatic tooth injuries.^{16–18} In the literature, there is only one available in vitro study performed by Iikubo et al., in which the authors evaluated oblique root fractures using 2 types of dental radiographs (right angle and bisecting angle technique; apparatus DX-1, GC Co., Tokyo, Japan) and CBCT (CB

Throne tomography, Hitachi Medical Corp., Tokyo, Japan, 10 × 10 cm field of view, with a resolution of 200 μm).¹⁹ Human central incisors were used in the experiment. The roots were divided into 3 groups: in the 1st one, transverse fractures at an angle of 90° to the long axis of the tooth were generated, in the 2nd and 3rd one, fractures at 75° and 55° were induced. Roots were cut with abrasive discs of various thicknesses (0.15 mm, 0.25 mm, 0.35 mm) at appropriate angles until the root canal was reached. The roots were not broken and glued together as in our study, thus to compare the outcomes of both studies, we selected the group of roots with the smallest groove width of 0.15 mm, which was closest to the fissure width evaluated in our experiment. Iikubo et al. noticed that grooves performed at an angle of 75° were poorly visible on radiographs taken with the bisecting angle technique.¹⁹ The same situation occurred on radiographs taken with the right angle technique, where radiographs taken at an angle of 55° were not

well visualized. According to the authors, the results clearly indicate difficulties in diagnosing such fractures using X-ray images.

In compliance with the studies of cited authors,¹⁹ the sensitivity for CBCT scans in the detection of fractures at an angle of 75° was 94% as compared to 75% for radiographs taken with the paralleling technique and 12% for the Cieszynski's rule of isometry technique. For fractures induced at an angle of 55°, the volumetric evaluation showed a sensitivity of 96%, and a radiographic examination presented a sensitivity of 13% and 98%, respectively. The results from the mentioned data indicated that the cone beam CT appeared to be the most efficient modality for detecting the discussed fractures. Moreover, as regards radiographs, it should be added that the closer the angle of incidence of the radiation beam to the plane of fracture occurred, the better the fracture fissure was shown. This finding is in line with other literature reports.^{20,21}

In the present study, the sensitivity of CBCT scans was 95.8%, whereas that of the radiographs taken in the right angle technique was 33.3%. Therefore, it can be concluded that the angle of incidence of the central ray in the paralleling technique while taking radiographs was close to the plane of the course of the fracture fissure only in 1/3 of the cases.

Specificity was a subsequent studied parameter. Iikubo et al. did not record any statistically significant differences in the values of this indicator for the evaluated radiological methods (100% CBCT, 96% right angle technique, 82% bisecting angle technique).¹⁹ We did not observe differences in the specificity in our study either. In both methods used, the discussed parameter was 100%.

Among the slices used for the evaluation of fractures, the contiguous one appeared to be most efficient. There are no publications on this subject in the available literature; therefore, this parameter cannot be compared with the findings of other authors.

Iikubo et al. also presented the aspect of inter-observer agreement.¹⁹ The evaluation was performed by 7 radiologists with more than 10-year professional work linked into pairs (21 pairs). After calculating the kappa coefficient for particular radiological methods, the highest value was found for volumetric tomography (0.83), followed by the paralleling technique (0.68) and the Cieszynski's rule of isometry (0.51). It can be observed that the results of our study are similar – 0.92 for CBCT and 0.70 for radiographs with the use of the right angle technique.

Clinical implications of the present study are worth emphasizing. As can be concluded from literature reports,^{16–18} despite different projections of radiographs, oblique root fractures are frequently identified as horizontal ones. Bornstein et al. evaluated 44 cases of fractures, which were diagnosed on the basis of radiographs as horizontal root fractures.¹⁸ The examination of volumetric scans demonstrated that 68.2% of them had an

oblique course of the fracture fissure. Additionally, a fracture, which on a conventional radiograph was located in the middle or apical third of the root, on sagittal slices from palatal aspects is extended towards the tooth cervix.

Moreover, the authors noticed that the image of the horizontal fracture observable on the radiographs and CBCT scans from the vestibular aspect indicated a similar location of the fissure in 70.5% of the cases contrary to radiographs and scans taken from the palatal aspect, which confirmed the location of the fissure in only 31.8% of the cases.

In the clinical setting, artifacts may occur during the diagnosis of dental root fractures with the use of CBCT. They derive from radiopaque materials, such as gutta-percha and sealers used during root canal filling, metals from prosthetic appliances or are associated with the patient's movement during CBCT scanning. Image distortions in the form of star-shaped streaks imitating fracture gaps may affect the diagnostic value of CBCT examinations.^{22–24}

However, it should be emphasized that the software in CBCT examinations allows dental practitioners to view teeth in at least 5 slices and different planes as well as from many angles. The fracture visible on 5, 4, 3 or even 2 slices of a particular scan enables clinicians to make a proper diagnosis.

The proper location of the fissure in the tooth with horizontal fracture allows dental practitioners to undertake adequate therapeutic management, i.e. root canal treatment or apicectomy. Idiopathic healing is also possible. Oblique root fracture is usually an indication that a tooth extraction is necessary. Treatment of such a fracture is always associated with failure, additionally leading to the loss of the alveolar bone, which makes further implant therapy more difficult.

Conclusions

The study indicated that CBCT is an effective method in diagnosing oblique dental root fractures. A contiguous slice appeared to be most effective in imaging oblique root fractures. The observer's experience did not play a significant role in the detection of oblique root fractures by means of CBCT.

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