RESEARCH ARTICLE

Diagnosis of alveolar and root fractures in macerated canine maxillae: a comparison between two different CBCT protocols

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Objectives: To compare two small-field-of-view (FOV) CBCT protocols with different voxel sizes and number of frames for the diagnosis of root and alveolar fractures in macerated canine maxillae.

Methods: 80 incisor teeth from the canine species were inserted in 80 anterior alveolar sockets of 20 canine maxillae. An operator randomly divided each maxilla site (80 sites in total) into 4 equal groups of 20 sites: 1 (sound tooth and non-fractured alveolar socket); 2 (sound tooth and fractured alveolar socket); 3 (fractured root and non-fractured alveolar socket); and 4 (fractured root and fractured alveolar socket). The CBCT images were obtained using two different protocols: normal (N) (voxel 0.20 mm, 400 frames and radiation exposure 5.6 mGy) and high definition (HD) (voxel 0.15 mm, 500 frames and radiation exposure 7.0 mGy).

Results: Sensitivity numbers for alveolar fractures were lower than specificity, resulting in comparable areas under the receiver operating characteristic curves (AUC) for both protocols. Sensitivity, specificity and AUC for N and HD protocols were very similar for root fractures. When comparing AUC for both N and HD protocols by submitting them to Student's *t*-test, the comparison among the curves produced statistically non-significant results for alveolar fractures and root fractures likewise.

Conclusions: Our findings demonstrated that the elected protocol for the diagnosis of root and alveolar fractures was N. This protocol allowed similar diagnosis results than HD protocol; however, with a lower amount of radiation exposure for the patient (5.6 mGy for N vs 7.0 mGy for HD).

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Introduction

Dentoalveolar trauma may occur after accidental falls, automotive accidents, violence/assault, contact sport injuries or accidents associated with the use of wheeled devices such as bicycles, skateboards, scooters or roller

skates, both in children and adults.^{1,2} Trauma may result in tooth fracture (crown and/or root, with or without pulpal exposure) and/or alveolar process injury.^{3,4}

Fracture diagnosis is achieved through clinical and radiographic imaging. The radiographic methods supported by dental trauma guidelines⁵ and thus elected by dental practitioners are periapical and topographic occlusal radiographs. Since these methods constitute two-dimensional images of the examined area, it is not possible to visualize the fracture in some cases. For those cases where the fracture is not evident in intraoral

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radiographs, CBCT images may be used to confirm the fracture and analyze the tooth and adjacent alveolar bone.⁶ Appropriate root fracture location and direction along with osseous fragment location and size reached by CBCT may lead to a proper treatment plan.^{7–12}

CBCT images are acquired *via* an X-ray beam source that focuses towards a detector. The captured images are processed by a software and transformed into axial, coronal and sagittal images (multiplanar reconstruction). Thus, an important advantage that CBCT has over periapical radiography is the capability of observing the acquired images simultaneously in three different plans. The availability of a third planes that is provided by CBCT allows the professional to observe the image in length, height and depth.¹³

CBCT is widely used in various fields of dental science, such as endodontics, orthodontics, oral pathology, implantology, periodontics and surgery.^{14,15} However, there is always a concern as to the radiation dose when the clinician prescribes a CBCT examination for a patient, especially if the patient is a child or adolescent.⁶ Variations in kV or mA,¹⁶ field of view (FOV),¹⁷ voxel size^{17–20} or number of frames²¹ in the same CBCT equipment can lead to an increase or decrease in radiation exposure for the patient. For root fractures, literature demonstrates that small FOV and voxel size CBCT images produce better diagnosis results.^{22–25}

In the current study, we used an *in vitro* model (macerated canine maxillae)^{26–28} to determine sensitivity, specificity, accuracy and inter- and intraobserver agreement between two CBCT protocols in the same tomograph. In addition, these results allowed us to nominate which protocol was more appropriate according to the “as low as diagnostically acceptable” principle.²⁹ Thus, the aim of this study was to compare two small-FOV CBCT protocols with different voxel sizes and number of frames, and consequently, different radiation exposure values for the diagnosis of root and alveolar fracture.

Methods and materials

Preparation of samples

80 incisor teeth from a canine species (*Canis lupus familiaris*) were inserted into 80 anterior alveolar

sockets of 20 macerated canine maxillae for this study. The sockets were previously inspected for the absence of fractures and the teeth were inspected for the absence of cavities, root resorption and fractures.

The Ethics Committee for the Use of Animals at University of São Paulo School of Dentistry exempted this research from approval under the protocol number 011/2015.

With the assistance of a website (www.random.org; Randomness and Integrity Services Ltd, Dublin, Ireland),²¹ an operator randomly divided each maxilla site (80 sites in total) into 4 groups: Group 1 (sound tooth and non-fractured alveolar socket—20 sites); Group 2 (sound tooth and fractured alveolar socket—20 sites); Group 3 (fractured root and non-fractured alveolar socket—20 sites); and Group 4 (fractured root and fractured alveolar socket—20 sites).

For the alveolar fracture, an innovative technique was developed. First, the maxillae were prepared with modelling wax (Lysanda, São Paulo, Brazil) around the alveolar process. This step was important for maintaining the bone fragments in position after the fracture (simulating gingival tissue) during image acquisition. Afterwards, the operator inserted an individualized metal bolt (with its diameter smaller than the alveolar socket diameter) inside the toothless socket. Another person maintained the maxilla in position and held buccal and palatine cortices with the thumb and index finger. The first operator applied a force at the bolt head with a hammer. The bolt tip produced a pressure at the bone resulting in the alveolar fracture (Figure 1a). Confirmation of the fracture was made by visual inspection.⁶

The same operator induced the root fracture in 40 teeth. For this purpose, each tooth was placed on a horizontal soft foundation and a hammer was used to apply a perpendicular force. The fragments were glued with cyanoacrylate adhesive (SuperBonder, Henkel, São Paulo, Brazil) as previously described by Costa et al²² and Hassan et al²⁰ (Figure 1b,c). The resulting fractures were horizontal, and after they were attached with the adhesive, they were not visible to the human eye. The sound or fractured tooth was then inserted in the socket and kept in position with the aid of a piece of base plate wax sheet (Lysanda). The wax sheet piece was juxtaposed to the teeth and sockets, recovering all four sites simultaneously.

Figure 1 (a) Alveolar fracture induced with metal bolt and hammer as described in the “Preparation of samples” section. (b) Sound tooth (before induced fracture). (c) Tooth with root fracture (before it had been glued with cyanoacrylate-based adhesive).

Figure 2 Macerated canine maxilla positioned at the tomography base with the aid of a condensation silicone dental putty supporting device.

Image acquisition

CBCT images were obtained using Planmeca ProMax[®] 3D (Planmeca Oy, Helsinki, Finland) using two different protocols, as follows: normal protocol—N (80 kVp, 8 mA, small FOV 5 × 5.5 cm, voxel 0.20 mm, 400 frames and 5.6 mGy of radiation exposure); high-definition (HD) protocol—HD (80 kVp, 8 mA, small FOV 5 × 5.5 cm, voxel 0.15 mm, 500 frames and 7.0 mGy of radiation exposure). The radiation exposure values were provided by the tomograph software.

Condensation silicone dental putty (Zetaplus, Zhermack SpA, Badia Polesine, Italy) was used to position the maxilla on the tomograph base (Figure 2).

CBCT assessment

CBCT images were imported into OsiriX MD (Pixmeo, Geneva, Switzerland; <http://www.osirix-viewer.com/>), a digital imaging and communications in medicine

viewer for MacOS (Apple, Cupertino, USA). The images were randomized in a website (www.random.org; Randomness and Integrity Services Ltd, Dublin, Ireland)²¹ and analyzed on an iMac 27-inch Mac OS X (Apple) workstation by two blind calibrated oral and maxillofacial radiologists who were not involved in either the alveolar and root fractures induction or in images acquisition. To assess intraobserver agreement, all images were evaluated by both observers after a 2-week interval. The observers were allowed to use all the software features to perform the analyses. Alveolar and root fractures were analyzed independently.

The image analyses criteria were acquired images *vs* the gold standard (sound or fractured root, and non-fractured or fractured alveolus) and correct location of fracture. The fractures present or absent were identified as 0 (fracture absence) and 1 (correctly located fracture presence). For analyzing the correct location of the fracture, alveolar fractures were categorized as buccal (B) or palatine (P), and root fractures were classified as apical (A), median (M) or cervical (C) third. All incorrectly diagnosed fracture locations were considered misdiagnosis and thus added to the 0 (fracture absence) category for statistical analysis purpose (Figure 3a,b).

Data analyses

The observers' diagnosis results were categorized and compared with the gold standard.

The kappa coefficient for intra- and interobserver analyses were calculated in an Excel[®] (Microsoft, Redmond, USA) spreadsheet and classified as slight (0.00–0.20), fair (0.21–0.40), moderate (0.41–0.60), good (0.61–0.80) and excellent (0.81–1.00) agreements.⁶

The scores were tabulated and inserted in a software previously used in the literature (MedCalc, Ostend, Belgium).³⁰ This software calculated sensitivity, specificity and area under the receiver operating characteristic curve (AUC).²¹ Student's *t*-test was performed between the areas, with a significance level of 5%

Figure 3 (a) CBCT sagittal imaging (protocol N)—root fracture at the cervical third (white arrow). (b) CBCT axial imaging (protocol N)—alveolar fracture at the palatine aspect of alveolar bone (white arrow).

Table 1 Kappa coefficient calculations for alveolar fractures and root fractures

CBCT protocols	Alveolar fractures			Root fractures		
	Observer 1		Observer 2	Observer 1		Observer 2
	First vs second observation	First vs second observation	Observer 1 vs 2	First vs second observation	First vs second observation	Observer 1 vs 2
Normal	0.47	0.77	0.30	0.80	0.73	0.76
HD	0.56	0.75	0.31	0.88	0.83	0.85

HD, high definition.

(p -value <0.05). Data analyses were performed independently for root fractures and alveolar fractures.

Results

Table 1 displays inter- and intraobserver agreement for CBCT protocols N and HD, for alveolar and root fractures independently. For alveolar fractures, the kappa values for intraobserver agreement ranged from moderate (0.47 for Observer 1) to good (0.77 for Observer 2), although interobserver agreement values were only fair (0.30 and 0.31). Alveolar fracture diagnosis agreements for both intra- and interobserver calculations indicated that the observers had some difficulty while performing this type of interpretation.

When root fracture kappa coefficients were analyzed, Table 1 presents values ranging from good to excellent agreement for both intra- (varying from 0.73 to 0.88) and interobserver (0.76 and 0.85) agreements, demonstrating that root fractures were easier to visualize than alveolar fractures.

Sensitivity, specificity and AUC are presented in Table 2 (p -value <0.0001), separately for alveolar and root fractures, in both CBCT protocols. When analyzing alveolar fractures, sensitivity (0.51 for protocol N and 0.54 for protocol HD) values are notably lower than specificity (0.83 for protocol N and 0.85 for protocol HD). These results indicated that the observers were more rigorous when detecting non-fractured sockets (true negatives) than when detecting fractured sockets (true positives). Similar AUCs were established in both CBCT protocols (0.67 for protocol N and 0.70 for protocol HD). Accuracy values *per se* are influenced by sensitivity and specificity values, while AUC is affected by the relationship between true-positive and false-negative thresholds for distinguishing fractures from non-fractures.

Table 2 Sensitivity (Se), Specificity (Sp) and area under the receiver operating characteristic curve (AUC) for alveolar fractures and root fractures

CBCT protocols	Alveolar fractures			Root fractures		
	Se	Sp	AUC	Se	Sp	AUC
Normal	0.51	0.83	0.67	0.93	0.87	0.90
HD	0.54	0.85	0.70	0.92	0.91	0.91

HD, high definition.

p -values <0.0001 .

For root fractures, sensitivity, specificity and AUC in Table 2 presents high values in both N and HD CBCT protocols. The numbers varied from 0.87 to 0.93. Especially for this type of fracture, both N and HD protocols had similar performances, however, with different levels of radiation exposure (N 5.6 mGy, and HD 7.0 mGy).

Table 3 presents AUC for both N and HD protocols, individually for Observers 1 and 2, first and second observations, for root and alveolar fractures separately. When submitted to Student's *t*-test, the comparison among AUCs produced statistically not-significant results (p value >0.05) for alveolar fractures and root fractures likewise. These results meant that AUCs obtained by protocols N and HD were similar.

Discussion

In all statistical analyses, results for alveolar fractures presented lower numbers than for root fractures. The kappa values for alveolar fractures ranged from fair to good, whereas root fractures resulted in good to excellent score ranges, leading us to consider that it is more difficult to diagnose alveolar fractures in CBCT in macerated canine maxillae. This may be explained by a larger amount of nutrient canals in the canine alveolar maxillary bone when compared with human maxillary bone, producing false-positive results. The absence of soft tissue in our maxillae may have influenced the diagnosis of alveolar fractures due to the inadequate attenuation of X-ray beams, differently from what occurs *in vivo*. Besides that, the methodology employed to produce alveolar fractures resulted in either complete or incomplete fractures. The presence of complete or incomplete alveolar fractures may be observed in human maxilla.³¹ Incomplete

Table 3 Alveolar fractures and root fractures—area under the receiver operating characteristic curve (AUC): Observers 1 and 2 (first and second observations independently)

CBCT protocols		Alveolar fractures		Root fractures	
		Normal	HD	Normal	HD
Observer 1	First observation	0.600	0.637	0.900	0.925
	Second observation	0.613	0.700	0.925	0.913
Observer 2	First observation	0.738	0.738	0.838	0.875
	Second observation	0.725	0.713	0.925	0.938

HD, high definition.

alveolar fractures occasionally produced false-negative results.⁶

Alveolar fractures occur concomitantly with lateral luxation, intrusion, avulsion or trauma resulting in alveolar displacement.^{3,32–38} Alveolar fracture diagnosis is fundamental because it may result in pulpal necrosis, tooth loss, external root resorption or alveolar bone loss.⁴ According to Diangelis *et al*³⁹ and Patel *et al*,⁴⁰ after fracture detection, it is necessary to reposition and immobilize the bone fragments for 4 weeks, suture lacerated soft tissues, administer antibiotic therapy when necessary and provide clinical and radiographic follow-up.

In the majority of the images, it was possible to observe a hypodense area at the periapical portion of the alveolar socket sites. This happened because the sockets and teeth were non-homologous. Both sound and fractured teeth inserted in the alveoli were not necessarily homologous (teeth that originally belonged to their correspondent alveolar socket). Consequently, the correlated CBCT images might or might not have a gap between the tooth apex and socket. This allocation did not influence the observers' analyses.

During root fracture induction, teeth with three or more fragments were excluded and substituted by another one. We opted for maintaining our methodology, since we believe that these images might represent a tooth dislocation at the socket (clinically, a lateral luxation may lead to this situation even in the absence of root or alveolar fractures), mimicking the different clinical situations in our study model (Groups 1, 2, 3 and 4), hence not influencing the diagnosis results. Furthermore, there are other *in vitro* studies that accommodated non-homologous teeth for root fractures diagnosed by CBCT images.^{41,42}

With regard to root fractures, the clinician has to evaluate the fracture direction (horizontal, vertical or oblique) and location (cervical, median or apical third). In our study, the employed methodology^{20,22} produced exclusively horizontal fractures. Hence, the observers analyzed the absence or presence of root fracture only, with no requirement of analyzing the fracture direction. When root fracture was present, its location had to be determined as well. The numerically high results for sensitivity, specificity and AUC for both N and HD protocols ascertain that a correct diagnosis was achieved in approximately 90% of the cases. Clinically, however, it is possible to diagnose vertical and oblique fractures as well. *In vitro*⁴³ and *in vivo*⁴⁴ studies investigated the diagnosis of vertical root fractures in CBCT images and both presented good diagnosis results, thus corroborating our study.

It is essential to diagnose root fracture location correctly because treatment is dependent on how apically the fracture occurred. Root fractures in the cervical third present poor prognosis and its treatment requires coronal fragment removal, apical fragment orthodontic extrusion and restoration, or tooth extraction and implant placement.⁴⁵ Median and apical root fractures

require clinical and radiological follow-up. According to Leathers and Gowans¹¹ and Patel *et al*,⁴⁰ there is frequently an interposition of connective tissue between the root fragments with no impairment of the tooth function. However, it is also important to inspect pulp vitality and integrity of apical neurovascular supply. Fractured teeth that present damage to apical neurovascular supply have poor prognosis in terms of pulp necrosis.¹² Vertical root fractures present poor prognosis associated with periodontal bone loss, whereas oblique root fractures may have a comminution aspect at the periapical radiograph, however, with a good prognosis after clinical and radiological follow-up.^{46,47}

Several authors^{24,41,48,49} associated a larger number of frames (and thus, a smaller voxel size) with better accuracy results for root fracture diagnosis. In our study, we designated two protocols with the same kV and mA, although with different number of frames. Small FOV was adopted in both protocols to expose only the diagnostically relevant area. During imaging acquisition, each protocol produced distinct radiation exposure effective doses (5.6 mGy for N and 7.0 mGy for HD protocols). Choi and Ford⁵⁰ studied radiation dose in child, adolescent and adult phantom heads while using the same CBCT parameters and concluded that the highest levels of absorbed dose occurred in child phantom head, thus the importance of using a CBCT protocol that ensures a lower radiation exposure when examining children. In our study, statistical analyses for both alveolar and root fracture diagnoses resulted in not significant difference when both protocols were compared. Many studies have been performed on root fractures; however, further studies on alveolar fractures are necessary to broaden the knowledge over this subject.

When the periapical radiograph does not provide enough information, CBCT is the next examination of choice for root and alveolar fracture diagnosis. A three-dimensional imaging method allows a more thorough visualization because it eliminates the superimposition of structures.¹³ Also in several studies, both *in vitro* and *in vivo*^{13,20,26,33} affirmed that CBCT is a more accurate diagnostic method when compared with periapical radiographs for diagnosis of root fracture. However, the clinician has to follow the “as low as diagnostically acceptable” principle²⁹ and, thus, invariably consider that CBCT examination will result in a larger amount of radiation exposure for the patient than the periapical radiograph.

Conclusions

Our findings demonstrated that the elected protocol for the diagnosis of root and alveolar fractures was N. This protocol allowed similar diagnosis results than HD protocol, however, with a lower amount of radiation exposure for the patient.

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