A CLINICAL EVALUATION OF CONE BEAM COMPUTED TOMOGRAPHY

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

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ABSTRACT

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Introduction: Cone beam computed tomography (CBCT) has become a valuable diagnostic tool for endodontics. Although the literature generally supports the accuracy of this imaging modality, some studies report that CBCT images may have limitations in representing the true clinical presentation. **Purpose**: This study compared pre-surgical limited field of view (LFOV) CBCT images with the actual clinical presentation. **Method**: Patients were asked to enroll in the study if they required endodontic surgery and had a limited FOV CBCT. A total of 45 subjects were enrolled. A standardized set of questions assessing presence and dimensions of bony defects, and presence of root fractures was prepared. During surgery, clinical data were collected and documented with photographs. At the conclusion of enrollment, the CBCT images were evaluated by three calibrated board certified endodontists. The clinical presentation data were compared to data from CBCT interpretations. **Results**: The CBCT evaluators correctly identified the presence of buccal plate perforations 95% of the time with 96% sensitivity and 94% specificity. The area of buccal plate perforation and apical lesions measured on the CBCT correlated with clinical measurements, with the exception of large defects. As the lesion size increased, CBCT underestimated the areas. There was no significant difference between the CBCT interpretation and clinical presentation of buccal bone vertical dimension measurements. When assessing for sinus communications, CBCT interpretation agreed with the clinical presentation 79% of the time, with a 50% sensitivity and 83% specificity. Evaluators using limited FOV CBCT's were unable to detect root fractures when present (20% sensitivity), but could rule out the presence of a fracture (100% specificity). **Conclusion**: Though useful in endodontic surgical treatment planning, the LFOV CBCT image should not be considered an identical representation of the clinical presentation at surgery.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

I. INTRODUCTION

Radiology plays a critical role in endodontics to help determine the diagnoses, develop treatment plan options, and assess prognoses. When endodontic surgery is considered, a thorough understanding of the surgical site is required. Traditionally, periapical and panoramic radiographs have been utilized to assess the regional anatomy, presence and dimensions of endodontic pathoses, height of alveolar bone, and possibility of root fractures (1). However, these imaging modalities are two-dimensional representations of three-dimensional structures. Therefore, interpreting the radiographs accurately can be adversely affected by structure overlap and distortion (2,3).

Cone beam computed tomography (CBCT) addresses many limitations of traditional radiography by providing three-dimensional imaging of hard tissue. Limited field of view (LFOV) CBCT offers a further advantage by creating high definition images with voxels less than 0.1mm (1). This technology has proven valuable for endodontic surgery by assessing root length and angulation, bone dimensions, and the proximity of vital structures such as the inferior alveolar nerve canal, mental foramen, and maxillary sinus (2). As a result, CBCTs have become an increasingly popular component of the modern endodontic practice (1,2).

While CBCT's capabilities provide many advantages, there are several limitations with this technology. For instance, the high resolution offered with the LFOV is less than digital intraoral radiography (2). Artifacts, such as scatter and beam hardening, can reduce the diagnostic quality of the images (1). Additionally, partial volume averaging can lead to misrepresentation of hard tissue dimensions (4,5).

Studies performed utilizing CBCT have made varying conclusions regarding its ability to accurately reflect hard tissue anatomy. Some authors have reported very high accuracy of linear measurements made with CBCT (6,7,8). Other studies have demonstrated CBCT to be inaccurate in certain cases. Sun et al described how CBCT images overestimated the dimensions of thick cortical bone, but underestimated the dimensions of thin cortical bone (5). Leung et al discovered that CBCT accurately assessed bone dimensions, but over reported fenestrations (9). Chavda et al reported CBCT to have a poor ability to detect vertical root fractures (10). Studies reporting the accuracy of CBCT images have primarily based measurements on *in vitro* or animal models. To date, there have been limited *in vivo* studies investigating the potential discrepancies between pre-surgical CBCT images and the clinical presentation. The purpose of this *in vivo* study was to compare radiographic interpretation data from LFOV CBCT images to clinical data collected during endodontic surgical procedures.

II. MATERIALS AND METHODS

This IRB approved study was conducted in the Endodontics Department at the Naval Postgraduate Dental School (NPDS), Bethesda, MD and was divided into four phases: diagnostic, surgical, radiographic, and data analysis.

<u>Diagnostic Phase:</u>

All patients received a comprehensive endodontic evaluation following established clinical guidelines prior to receiving care. In cases where endodontic surgery was indicated, a LFOV CBCT was often prescribed and taken in accordance with the 2015 AAE/AAOMR guidelines. Patients were invited to participate in this study if they were eighteen years of age or older, required endodontic surgery, and had a LFOV CBCT of the surgical area. Forty-five subjects meeting the inclusion criteria were consented and enrolled, thirty-four prior to the surgical procedure and eleven following surgery.

Surgical Phase:

Multiple types of endodontic surgeries were performed on this cohort of subjects and included forty-one standard root-end surgeries, one combined root-end and root amputation surgery, and three resorption repair procedures. The surgical procedures were completed utilizing currently accepted microsurgical techniques. Clinical data were collected on a data collection sheet composed of 7 standardized questions (Figure 1.) and identified by a subject number only. Due to the variety of surgeries performed, clinical data were collected on those questions relevant to the procedure. All clinical measurements were captured utilizing a #15 UNC color-coded periodontal probe (Hu-Friedy LLC, Chicago, IL) to the nearest 0.5mm.

FIGURE 1: DATA COLLECTION SHEET

A CLINICAL EVALUATION OF CONE BEAM COMPUTED TOMOGRAPHY

SUBJECT NUMBER #________

Surgeon_________________________

Date__________

CBCT TAKEN_____

TOOTH #______

Marginal bone height ______mm. Take photo with perio probe ________
(Measured mid-buccal from CEJ or crown margin to crestal bone)

Perforation of cortical plate? Yes / No Take photo with perio probe________
Measurement: width______X height_______mm.

Communication with sinus or other structures? (IA canal, mental foramen, infraorbital canal) Yes / No Take photo ________
____

Dimensions of lesion width_____X height______X depth______mm.

Fracture? Yes / No **Type:**________ Take photo ________

Untreated canal(s) located? Yes / No Take photo________
_________________canal

Other findings
(fractured instruments, extruded material, root perforation, etc.) Take photo________

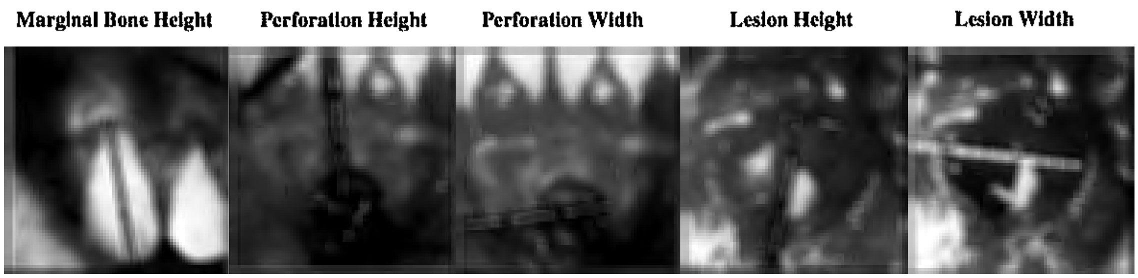
Immediately following flap reflection, the marginal bone height of the tooth receiving treatment was measured. This was defined as the distance between the cementoenamel junction (CEJ) and the alveolar bone crest on the mid-facial surface of the tooth. In teeth restored with a crown, the measurement was taken from the restoration margin to the bone crest.

The presence or absence of a buccal cortical plate perforation was the second observation. A perforation was defined as an opening on the surface of the bone large enough to permit insertion of the periodontal probe. If a perforation was present, the height (coronal-apical) and width (mesial-distal) at the points of greatest dimensions were measured.

Ostectomies were performed in root end surgical procedures. If a lesion was present, the tissue was removed and the crypt dimensions recorded. Width was measured mesial-distal and height coronal-apical at the greatest dimensions. Because the entire length of the periodontal probe did not fit into the crypts, the measurements were made in halves utilizing the root tip as a reference point. They were combined to establish the overall dimensions. After removal of the lesion, an observation was made as to whether the defect communicated with any surrounding anatomical structures, such as the maxillary sinus or inferior alveolar canal. If so, the communication was identified and recorded.

During root end procedures, the root was stained to inspect for vertical root fractures. If a fracture was detected, it was recorded. All clinical measurements and observations data were photographed for documentation (Figure 2).

FIGURE 2: CLINICAL MEASUREMENTS



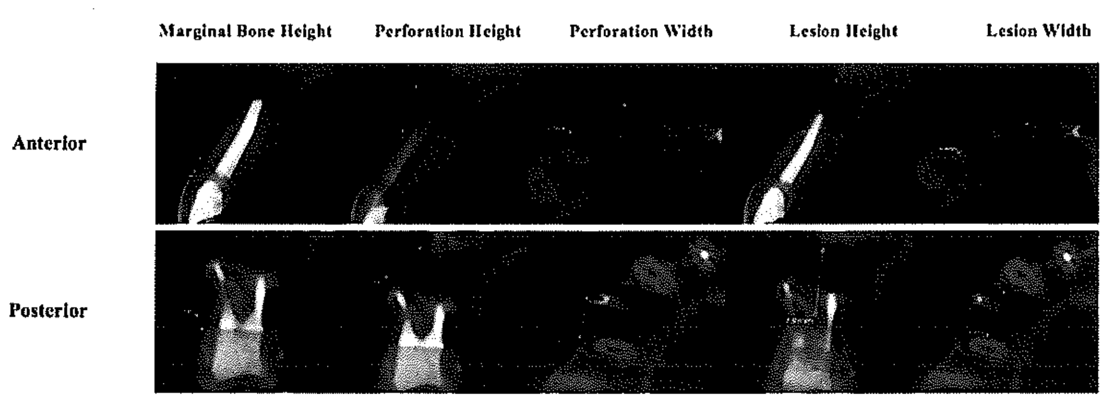
Radiographic Interpretation:

Eleven of the scans were taken with the Carestream (CS) 9000 (Carestream Dental LLC, Atlanta, GA) using the following exposure parameters: 65-90kV, 6-10mA, 10.8 seconds, field of view 5cm x 3.75cm and a voxel size of either 76μm or 100μm. Thirty-four of the scans were taken with the Carestream 9300 (Carestream Dental LLC, Atlanta, GA) using the following exposure parameters: 85kV, 8-12mA, 10.8-20 seconds, field of view was 5cm x 5cm, 90μm voxel size. The subjects' CBCT scans were de-identified and copied on to a Dell Inspiron 15.6" laptop PC (Dell Computer Corporation, Round Rock, TX) with the CS 3D (Carestream Dental LLC, Atlanta, GA) Imaging Software.

Three board certified endodontists with multiple years of experience in interpreting LFOV CBCT scans evaluated the images and provided the radiographic interpretation data. The examiners were calibrated as a group and shown two scans involving different teeth, #8 and #5, each with an apical lesion and buccal plate perforation. The principal investigator demonstrated how to use the CS 3D software to measure marginal bone height, presence and dimensions of perforations and lesions, and presence of sinus communications and vertical root fractures.

The orthogonal planes were aligned to each subject tooth so the axial plane was perpendicular, while the coronal and sagittal planes were parallel to the long axis. Measurements involving height (marginal bone height, perforation height, lesion height) were taken on the sagittal slice for anterior teeth and coronal slice for posterior teeth. Measurements involving width (perforation width, lesion width) were taken on the axial slice. The examiners were directed to scroll through the three planes when assessing for presence of vertical root fractures or sinus communication (Figure 3).

FIGURE 3: RADIOGRAPHIC MEASUREMENTS



Following the calibration, the examiners independently viewed the randomized forty-five LFOV CBCT scans on the laptop. The radiographic interpretation measurements and observations described in the calibration were recorded on a separate data collection sheets (Figure 1.) identified with the corresponding clinical data collection sheet subject number. The principal investigator collated all data collection sheets and organized them into a spreadsheet for final analysis.

Data Analysis:

The clinical data and corresponding radiographic interpretation data were analyzed utilizing R Core Team Software (R Foundation for Statistical Computing, Vienna, Austria, 2015). For the observational data regarding presence or absence of a finding (perforation, sinus, vertical root fracture), Chi Square was used to compare the clinical findings to a majority consensus of the 3 evaluators' radiographic interpretations. A kappa score was calculated to evaluate inter-evaluator reliability. Sensitivity and specificity of the CBCT image interpretations were calculated based on the evaluators' consensus and the clinical findings.

For the measurement data assessment, perforation and lesion areas were estimated by taking the product of the heights and widths for the radiographic and clinical values. Inter-evaluator reliability was assessed by calculating an intraclass coefficient (ICC) for the CBCT measurements of marginal bone height, perforation area, and lesion area. A linear regression model was then used to compare the radiographic interpretation data of all evaluators to clinical data for marginal bone height, perforation area, and lesion area.

III. RESULTS

The results are summarized in Table 1. Thirty-nine marginal bone height measurements were made, with an ICC of 0.68. The linear regression model demonstrated that the CBCT evaluators neither underestimated or overestimated this parameter (Fig. 4a).

TABLE 1

Observations	Accuracy	Sensitivity(%)	Specificity(%)	κ
Perforation	95	96	94	0.80
Sinus Perforation	79	50	83	0.65
Vertical Root Fracture		20	100	0.09

Measurements	ICC
Marginal Bone Height	0.68
Perforation Area	0.83
Lesion Area	0.95

Buccal plate perforation was assessed in forty-one cases, with a kappa score (κ) of 0.80. The overall accuracy of the CBCT evaluators was 95%, with a 96% sensitivity and a 94% specificity. When measuring the height and width of the perforations, the evaluators had an ICC of 0.83. The slope of the resulting regression line is less than one, suggesting that the CBCT evaluators tended to underestimate the dimensions of larger perforations (Fig 4b).

Nineteen apical lesions were measured, with an ICC of 0.95. In a manner similar to that of perforation area, the CBCT evaluators demonstrated a tendency to underestimate the areas as the lesion size increased (Fig 4c).

Fourteen maxillary posterior teeth were evaluated for communication of the lesion with the maxillary sinus. The ability of the evaluators to detect a sinus perforation with CBCT was variable with an overall accuracy of 79%, with a 50% sensitivity and 83% specificity. The agreement between the CBCT evaluators yielded a kappa score of 0.65 that reflected moderate congruence.

When evaluating for the presence of root fractures, the sensitivity of the CBCT evaluators was 20%, indicating the evaluators had difficulty in detecting root fractures when clinically present. On the other hand, a high specificity was noted at 100%, which meant the ability to detect non-fractured teeth was high. The kappa score for this parameter was 0.09 and reflected a higher degree of variability amongst the evaluators.

FIGURE 4: LINEAR REGRESSION ANALYSES

FIGURE 4a

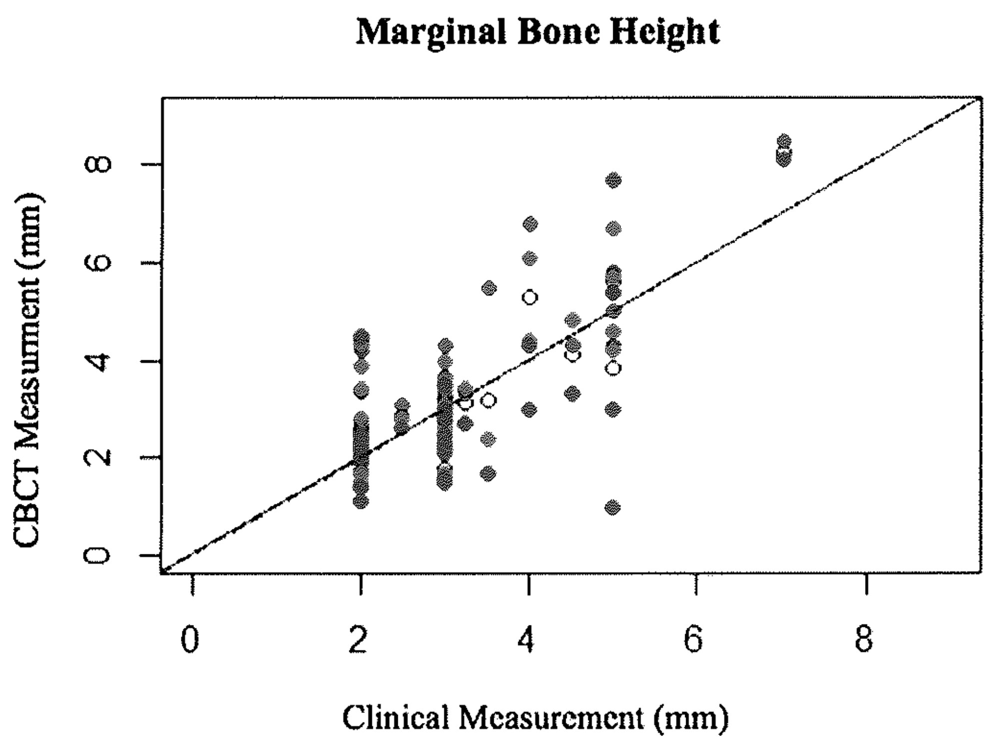


FIGURE 4b

Perforation Area

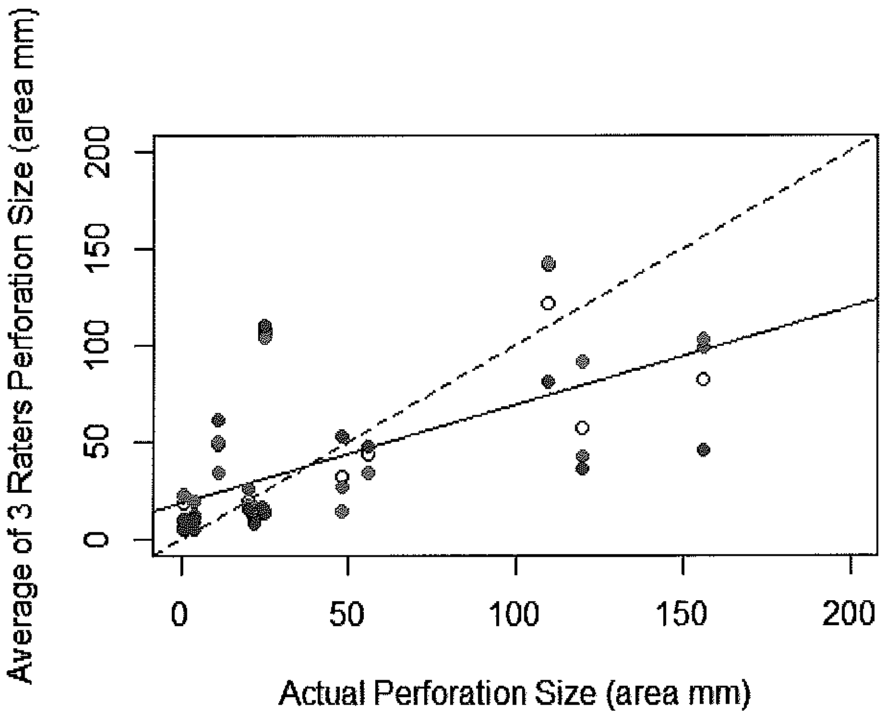
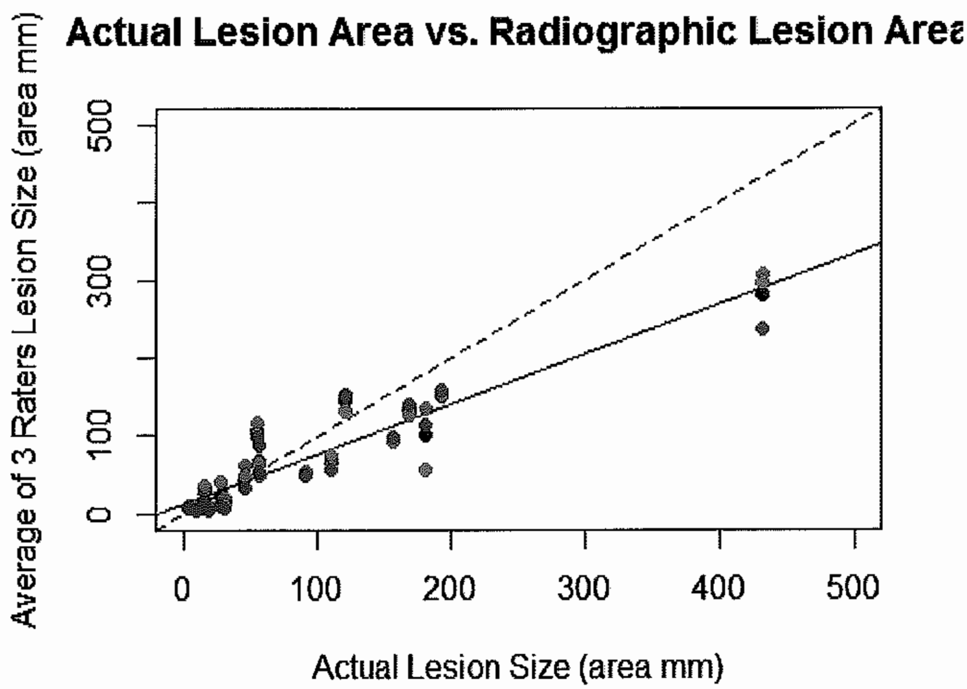


FIGURE 4c



IV. DISCUSSION

When performing endodontic surgery, a lack of appreciation of the regional anatomy can lead to adverse outcomes, such as iatrogenic damage to teeth, sinus exposure, or nerve damage. Cone beam computed tomography has proven to be a valuable adjunct due to the ability to make accurate measurements and visualize anatomy in three dimensions with minimal distortion (1,2). The ability to observe bony architecture in a preoperative surgical site preoperatively can enhance the surgical preparedness of the clinician (11). If a lesion is excessive in size and encroaches on the maxillary sinus, lingual plate, or inferior alveolar nerve, it is critical to determine this prior to surgery to avoid violating the borders and reduce postoperative morbidity. Lastly, CBCT is commonly utilized during the treatment planning phase to assess presence or absence of vertical root fractures, particularly in cases where the clinical and two-dimensional radiographic exam are suggestive of a fracture (ie: deep isolated perio probing, J-shaped radiolucency, etc.) (12).

Although CBCT has several advantages over two-dimensional radiography, it has limited resolution and can produce streaking and beam hardening artifacts in the presence of radiodense objects. Additionally, partial volume averaging can lead to misrepresentation of hard tissue. This occurs when the voxel is larger than the object it represents. To compensate for the discrepancy, the computer software displays the voxel as a weighted average of the various densities within (4,5). If a CBCT is interpreted at face value without considering these limitations, costly errors can be made carrying out treatment. For instance, a tooth may be deemed non-restorable due to lack of apparent bone support on a CBCT, when in fact a thin, yet normal cortical plate surrounds the tooth. Such mistakes can lead to unnecessary extractions of healthy teeth. Thus it is critical for clinicians to understand the limitations of CBCT and how to correctly interpret scans.

The results of this study demonstrate that CBCT is useful for detecting perforations in the buccal cortical plate, as well as measuring hard tissue dimensions. This is consistent with several studies that support the accuracy of CBCT (6-8,11,13-16). However, there was a tendency to over report the presence of bone in larger defects, and under report it in smaller defects. This is consistent with Sun and Leung in separate studies (5,9). It was noted in cases involving a thin cortical plate, there was a trend for the CBCT to under-report the thickness of cortical bone. Therefore, CBCT may give the impression that no bone is present when, in fact, a thin layer of bone exists. This can lead to an error in diagnosis and difficulty in determining prognosis.

When evaluating for presence of communication of the lesion with the maxillary sinus, the CBCT demonstrated limited utility with a sensitivity of 50% and specificity of 83%. In 10 of the 16 cases involving maxillary posterior teeth, evaluators identified a sinus perforation on the CBCT image when it was not clinically present. One of the commonly cited advantages of CBCT is that it allows visualization of the relationship between the roots of maxillary teeth and the sinus membrane, and there have been studies that base their results on measurements taken with CBCT (17). However, there is limited literature validating the use of CBCT for studying the relationships between the maxillary molar roots and the sinus membrane. A study by Howe was conducted on human cadavers and suggested the amount of bone separating the roots of the maxillary first molars and the sinus membrane is overestimated in CBCT images (18). Santos Junior et al, in a study conducted on porcine jaws, suggest that CBCT was inconsistent with detection of oroantral communication (19).

An interesting finding of this study was that measurements involving larger distances, as in the case of apical lesions, had a higher agreement amongst the evaluators. Meanwhile, the shorter distance measurements such as marginal bone height had less agreement. In a review article, Molen discussed how voxel size is often mistakenly equated with spatial resolution. However, a decreased voxel size can actually increase "noise" artifacts and result in poorer resolution than what would be expected (4). Therefore, short distance measurements may be more adversely affected by partial volume averaging, thus resulting in the higher degree of variability.

The usefulness of CBCT for detection of vertical root fractures is controversial, and the issue has been explored in both *in vitro* and *in vivo* studies. Kamburoğlu et al suggested that artificial fractures in human teeth were highly detectable with a LFOV CBCT (20), while Patel et al carried out a similar study and determined CBCT to be unreliable (21). When considering *in vivo* studies, Edlund et al concluded that LFOV CBCT has 88% sensitivity and 75% specificity (22), while Chavda et al discerned 27% and 83% respectively (10). The findings of the present study of 20% sensitivity and 100% specificity implies that CBCT has limited utility for detecting vertical root fractures, and thus agrees with Chavda et al. However, as this study only included five teeth with vertical root fractures, the results must be interpreted with caution. A greater sample size would likely yield more meaningful results. Talwar et al conducted a systematic review and meta-analysis of VRF detection with LFOV CBCT and discussed "heterogeneity varying from moderate to high," and concluded that although CBCT is generally far more effective for detection of VRF's than periapical radiographs, it still has limitations, particularly in cases of root-filled teeth (23).

V. CONCLUSION

In summary, the results demonstrate that LFOV CBCT is useful for detecting osseous defects. Furthermore, measurements taken with CBCT software are highly reproducible, and accurately reflect *in vivo* bony dimensions. However, the ability to detect root fractures with CBCT was severely limited. In conclusion, the LFOV CBCT should not be used as the gold standard for treatment planning purposes. Rather, it should be considered a valuable adjunct.

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