

A CLINICAL EVALUATION OF CONE BEAM COMPUTED TOMOGRAPHY

by

James S. Morris Jr., D.M.D.
Lieutenant Commander, Dental Corps
United States Navy

A thesis submitted to the Faculty of the
Endodontic Graduate Program
Naval Postgraduate Dental School
Uniformed Services University of the Health Sciences
in partial fulfillment of the requirements for the degree of
Master of Science
in Oral Biology

June 2018

Naval Postgraduate Dental School
Uniformed Services University of the Health Sciences
Bethesda, Maryland

CERTIFICATE OF APPROVAL


MASTER'S THESIS


This is to certify that the Master's thesis of

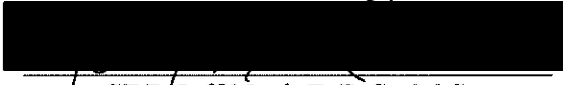
James S. Morris Jr.

has been approved by the Examining Committee for the thesis requirement
for the Master of Science degree in Oral Biology at the June 2018 graduation.

Thesis Committee:


CAPT Terry Webb, D.D.S., M.S.
Chairman, Endodontics


CDR Calvin Suffridge, D.D.S., M.S.
Thesis Supervisor


CDR/Jeff Neal, D.D.S., M.S.
Research Mentor

The author hereby certifies that the use of any copyrighted material in the thesis manuscript titled:

“A CLINICAL EVALUATION OF CONE BEAM COMPUTED TOMOGRAPHY”

is appropriately acknowledged and, beyond brief excerpts, is with the permission of the copyright owner.



James S. Morris Jr.
Endodontic Graduate Program
Naval Postgraduate Dental School
30 June 2018

NAVAL POSTGRADUATE DENTAL SCHOOL
JAMES S. MORRIS JR.

2018

This thesis may not be re-printed without the expressed written permission of the author.

Distribution Statement

Distribution A: Public Release.

The views presented here are those of the author and are not to be construed as official or reflecting the views of the Uniformed Services University of the Health Sciences, the Department of Defense or the U.S. Government.

ABSTRACT

A CLINICAL EVALUATION OF CONE BEAM COMPUTED TOMOGRAPHY

JAMES S. MORRIS JR.
D.M.D., ENDODONTICS, 2018

Directed by: CDR CALVIN SUFFRIDGE, D.D.S., M.S.
Naval Postgraduate Dental School

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 prospective, in vivo study compared limited field of view (LFOV) CBCT measurements to clinical measurements made during endodontic surgery.

Method: Patients requiring endodontic surgery with a LFOV CBCT were asked to enroll in the study. Data collection, during the surgical and radiographic assessment, involved answering standardized questions evaluating multiple factors including the presence and dimensions of bony defects and presence of root fractures. During surgery, clinical data were collected and photographically documented. During the radiographic assessment, CBCT scans were evaluated by three calibrated, board certified specialists; two endodontists and one oral and maxillofacial radiologist. The clinical data were compared to data from CBCT interpretations and statistically analyzed. **Results:** A total of 50 subjects, with 58 teeth were analyzed. The CBCT evaluators correctly identified the presence of buccal plate perforations 94% of the time, with 90% sensitivity and 100% specificity. The area of buccal plate perforation and apical lesion volume were generally underestimated on the CBCT. There was no significant difference between the CBCT interpretation and clinical presentation of vertical bone height. Evaluators were unable to detect root fractures radiographically when present (0% sensitivity), but were able to rule out the presence of a fracture (100% specificity), however, there was no agreement between evaluators.

Conclusions: Based on the results, CBCTs are accurate in identifying buccal plate perforations, have limitations when assessing the size of osseous defects and are unreliable when evaluating for root fractures. Though useful in endodontic surgical treatment planning, the LFOV CBCT image should not be considered an identical representation of the clinical presentation.

TABLE OF CONTENTS

CHAPTER		Page
I.	INTRODUCTION	7
II.	MATERIALS AND METHODS.....	10
III.	RESULTS	17
IV.	DISCUSSION.....	20
V.	CONCLUSIONS.....	22
REFERENCES	23

LIST OF FIGURES AND TABLES

Figure		Page
1.	CLINICAL DATA COLLECTION SHEET	11
2.	CLINICAL MEASUREMENTS	13
3.	RADIOGRAPHIC DATA COLLECTION SHEET.....	15
4.	RADIOGRAPHIC MEASUREMENTS.....	16
5.	LINEAR REGRESSION MODELS FOR LESION SIZE AND BUCCAL BONE PERFORATION SIZE.....	18
6.	LINEAR REGRESSION MODEL FOR MARGINAL BONE HEIGHT..	19
Table		Page
1.	SUMMARY OF RESULTS	17

I. INTRODUCTION

Straight-on and angled periapical (PA) radiographs have served as the primary diagnostic images in endodontics for many decades. A properly exposed PA radiograph can provide accurate linear dimensions of anatomic features, but to precisely localize structures in situ, a series of angled PAs must be taken.¹ Panoramic images, implemented in the 1960's, offered comprehensive images of maxillofacial structures but suffer from distortion and superimposition.² In the early 21st century, cone-beam computed tomography (CBCT) technology was introduced, offering image views from three orthogonal planes (coronal, sagittal, and axial). Its primary advantage is a three-dimensional rendered image generated from the image volume.

In 2001, NewTom introduced the first cone beam scanner for dental use. These devices employed the same controls found in conventional dental radiography units. Unlike conventional radiography, the x-ray beam of a CBCT is collimated into a pyramidal or cone shape.² This design covers a larger area, producing images more quickly and with approximately 76 to 99% less radiation when compared to traditional computed tomography (CT) scans.³ Other advantages of CBCT over CT include the ability to capture a sharper image⁴ and the CBCT field of view (FOV) can be further collimated to increase resolution and decrease the area of exposure (large, medium, or focused).¹ A focused or limited field of view (LFOV) CBCT, which covers an area of 5cm or less, is sufficient for most endodontic purposes.

When treatment planning for endodontic surgery, a thorough understanding of the surgical site is essential. This may include the presence and/or absence of apical bony lesions, alveolar bone defects, perforation of cortical bone, missed root canals, presence

of root fractures, adjacent anatomical structures, and previous procedural complications (i.e. fractured instrument, root perforation or extruded material). Traditional radiographic imaging modalities provide a two-dimensional representation of a three-dimensional surgical site, and thus hinder the clinician's ability to visualize all structures due to superimposition. This limitation can lead to misinterpretation during the treatment planning phase. The advent of CBCT has helped eliminate many of the limitations inherent to two-dimensional imaging modalities.

CBCT use in dentistry has been widely studied and is generally accepted as an accurate digital representation of the clinical scenario. Many investigations using simulated apical lesions in human cadaver models have shown that CBCT can accurately measure the volume of the lesions.^{5,6,7} Similar studies have also established the accuracy of CBCT measurements of apical lesions in animal models.^{8,9} de Paula-Silva et al. found that CBCT was highly accurate in detecting induced apical lesions in dogs when compared to periapical radiographs, verified with histopathologic findings.¹⁰ Even though multiple studies have shown positive results, Tsai et al. noted that limitations exist when lesions are less than 1.4 mm in diameter.¹¹

Likewise, many studies have used human cadaver models to determine the accuracy of CBCT in measuring the distance to adjacent anatomical structures, such as the maxillary sinus¹² or the mandibular canal.^{13,14} Other human cadaver models have used artificial landmarks to determine its accuracy.¹⁵ Al-Ekrish et al. suggested that CBCT was limited in this regard, as its accuracy is operator dependent.¹⁶

The accuracy of CBCT in representing alveolar bone defects has also been widely studied with mixed results, utilizing both human cadaver and animal models. Timock et

al. determined the modality to be accurate when measuring the height and thickness of alveolar bone.¹⁷ Limitations have also been noted by other investigators, more specifically in regards to voxel size¹⁸ and CBCT's tendency to over-estimate the amount of bone present.¹⁹ When detecting the presence of a fenestration or dehiscence, Leung et al. found CBCT to have a very low positive predictive value and a high negative predictive value.²⁰ Sun et al. also found inaccuracies with CBCT when measuring alveolar bone height, noting the modality tends to over-estimate the amount of bone loss.²¹

Very few *in vivo* studies have compared CBCT measurements with intraoperative findings. Behnia et al. compared buccal bone thickness during surgical extraction of maxillary anterior teeth and found that CBCT's accuracy was limited when the bone is thinner than 1mm.²² Banodkar et al. and Haas et al. compared periodontal bone defects on CBCT with intraoperative findings and found CBCT to be an accurate representation of the surgical site.^{23,24} Chavda et al. compared the ability of periapical radiographs and CBCT to detect vertical root fracture before extraction and found both modalities to be inaccurate.²⁵

To date, no human-use studies exist that compare LFOV CBCT measurements to clinical measurements documented during endodontic surgery. Understanding the accuracy of measurements obtained from LFOV CBCT interpretations can be of value to the clinician, particularly when determining the size of the periapical lesion, thickness of alveolar bone, and proximity to adjacent anatomic structures. The purpose of this prospective, *in vivo* study was to compare measurements from LFOV CBCT

interpretations to clinical measurements taken intraoperatively during endodontic surgery.

II. MATERIALS AND METHODS

This Walter Reed National Military Medical Center IRB approved study (protocol #383684) was divided into four phases: diagnostic, surgical, radiographic interpretation, and data analysis.

Diagnostic Phase

All patients received a comprehensive endodontic evaluation following established clinical guidelines prior to receiving treatment. In cases where endodontic surgery was indicated, a LFOV CBCT was obtained in accordance with the 2015 AAЕ/AAOMR guidelines for CBCT use in endodontics. Patients were invited to participate in this study if they met the following inclusion criteria: eighteen years of age or older, required endodontic surgery, and a LFOV CBCT of the surgical area was acquired.

Surgical Phase

The surgical procedures were completed utilizing currently accepted microsurgical techniques. Clinical data were identified only by subject number and documented on a data collection sheet composed of 7 standardized questions (Figure 1.) Clinical data varied from case to case and was collected only on those questions relevant to the procedure. All clinical measurements were made using a #15 UNC color-coded periodontal probe (Hu-Friedy LLC, Chicago, IL) to the nearest 0.5mm (Figure 2).

FIGURE 1: CLINICAL DATA COLLECTION SHEET

Version Sep2015

A CLINICAL EVALUATION OF CONE BEAM COMPUTED TOMOGRAPHY

REGISTRY PATIENT # _____

Surgeon _____

Date _____

CBCT TAKEN _____

TOOTH # _____

Vertical 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 (FIGURE 2a). This was defined as the distance

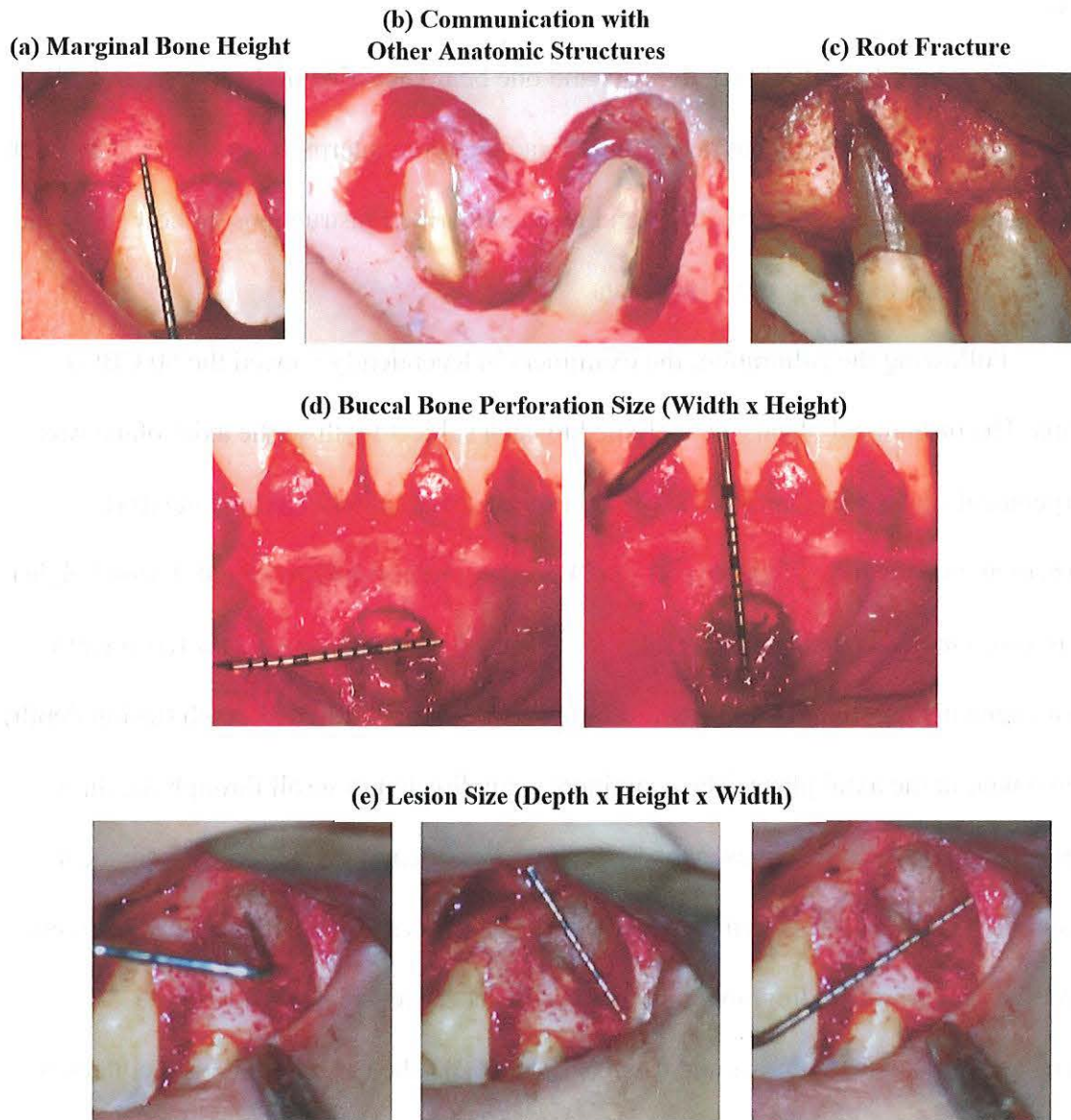
between the cementoenamel junction (CEJ) and the alveolar bone crest on the mid-facial surface of the tooth. In teeth restored with a crown, the measurement was taken from the restoration margin to the bone crest.

The presence or absence of a buccal cortical plate perforation was identified and documented. 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) were measured at the points of greatest dimensions (FIGURE 2d).

If a periapical lesion was present following hard tissue removal and access, the diseased tissue was removed via curettage. The crypt dimensions were recorded as follows: width was measured mesial-distal, height coronal-apical, and depth buccal-lingual at the greatest dimensions (FIGURE 2e). 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. The measurements were combined to establish the overall dimensions. After removal of the lesion, a determination 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 (FIGURE 2b).

If a root fracture was identified at any point during the procedure, it was recorded (FIGURE 2c). All clinical measurements and other findings were photographed for documentation.

FIGURE 2: CLINICAL MEASUREMENTS



Radiographic Interpretation Phase

All CBCT 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, 90 μ m voxel size. Each scan was anonymized and copied to a HP EliteBook Folio 1040 G3 Notebook PC (Hewlett Packard Enterprise, Palo Alto,

CA) and then reviewed with CS 3D Imaging Software (Carestream Dental LLC, Atlanta, GA).

Two board certified endodontists and one board certified oral and maxillofacial radiologist evaluated the scans and provided radiographic interpretation of the data. Each examiner was calibrated individually and provided written instructions on how to use the CS 3D software to collect the CBCT data.

Following the calibration, the examiners independently viewed the 50 CBCT scans. 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 in the sagittal plane for anterior teeth and coronal plane for posterior teeth. Measurements involving width (perforation width, lesion width) and depth (lesion depth) were taken in the axial plane. The examiners were directed to scroll through the three planes when assessing for presence of root fractures or communication with adjacent anatomic structures. Measurements and other findings described in the calibration were recorded on separate radiographic interpretation data sheets identified with the corresponding subject number and tooth (FIGURE 3). The radiographic data collected was then organized for statistical analysis.

FIGURE 3: RADIOGRAPHIC DATA COLLECTION SHEET

A CLINICAL EVALUATION OF CONE BEAM COMPUTED TOMOGRAPHY
Radiographic Reviewer Data Collection

REGISTRY PATIENT #
TOOTH #

Reviewer (circle one): 1 2 3

Date _____

Vertical bone height (measured mid-buccal from CEJ or crown margin to crestal bone)
_____ mm

Perforation of cortical plate? Yes / No

Measurement (to nearest tenth of mm):
Width _____ Height _____

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

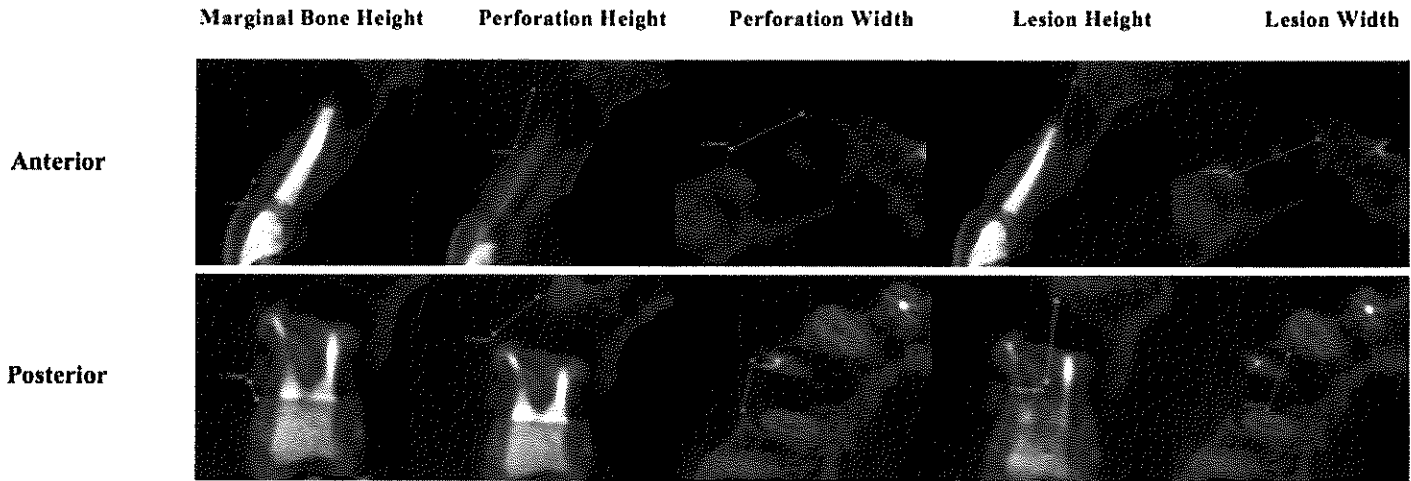
Dimensions of lesion (to nearest tenth of mm)
Width _____ Height _____ Depth _____

Fracture? Yes / No Type: _____

Untreated canal(s) located? Yes / No _____ canal

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

FIGURE 4: RADIOGRAPHIC MEASUREMENTS



Data Analysis Phase

During the data analysis phase, the clinical data and corresponding radiographic interpretation data were analyzed using R Core Team Software (R Foundation for Statistical Computing, Vienna, Austria, 2015). Categorical data in this study included: the presence of a buccal bone perforation, the presence of a root fracture, and communication with other structures (i.e. maxillary sinus or inferior alveolar nerve canal). These were analyzed for accuracy, sensitivity and specificity; and inter-rater agreement was represented with a kappa value. It should be noted that for this interim analysis, communication with other structures was not statistically analyzed due to limited data available. Continuous data included: buccal bone perforation size, lesion size, and marginal bone height. These were analyzed via linear regression models with intraclass correlation coefficients (ICC) calculated to represent inter-rater agreement. A power

analysis was performed and established the need for one hundred eleven (111) enrolled subjects.

III. RESULTS

For this interim analysis, 50 subjects were prospectively consented and enrolled prior to endodontic surgery, 11 subjects were retrospectively enrolled but their data were not used for this analysis. Two different types of endodontic surgeries were performed on this cohort, which included 48 standard root-end surgeries and 2 surgical root resorption repair procedures. This included a total of 58 teeth; 41 of which were maxillary and 17 were mandibular. A total of 31 subjects involved buccal bone perforations, there were 45 marginal bone height measurements, and 6 root fractures. The results are summarized in Table 1.

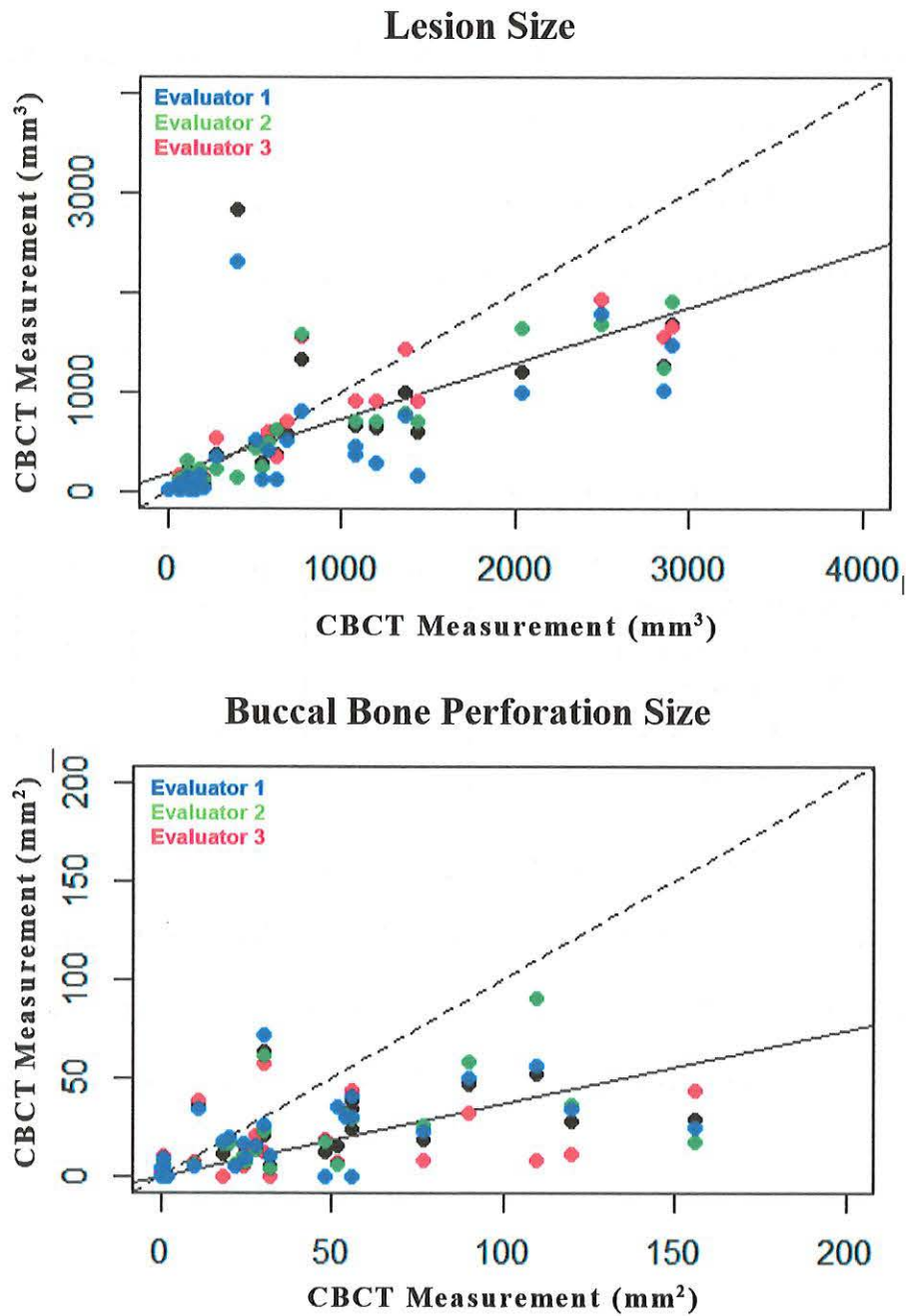
TABLE 1: SUMMARY OF RESULTS

	Accuracy	Sensitivity	Specificity	κ	ICC
Buccal Bone Perforation	94%	90%	100%	0.89	-
Root Fracture	-	0%	100%	0	-
Buccal Bone Perforation Size	-	-	-	-	0.61
Lesion Size	-	-	-	-	0.72
Marginal Bone Height	-	-	-	-	0.58

When evaluating for the detection of buccal bone perforations on CBCT, there was a 94% accuracy, with a 90% sensitivity (the ability to detect a perforation when present) and 100% specificity (the ability to detect the absence of a perforation). The kappa score for this measurement was 0.89, indicating high agreement between the evaluators.

For the both buccal bone perforation size and lesion size, the relationship between the CBCT evaluators' measurements and clinical measurements was plotted via linear regression models (FIGURE 5).

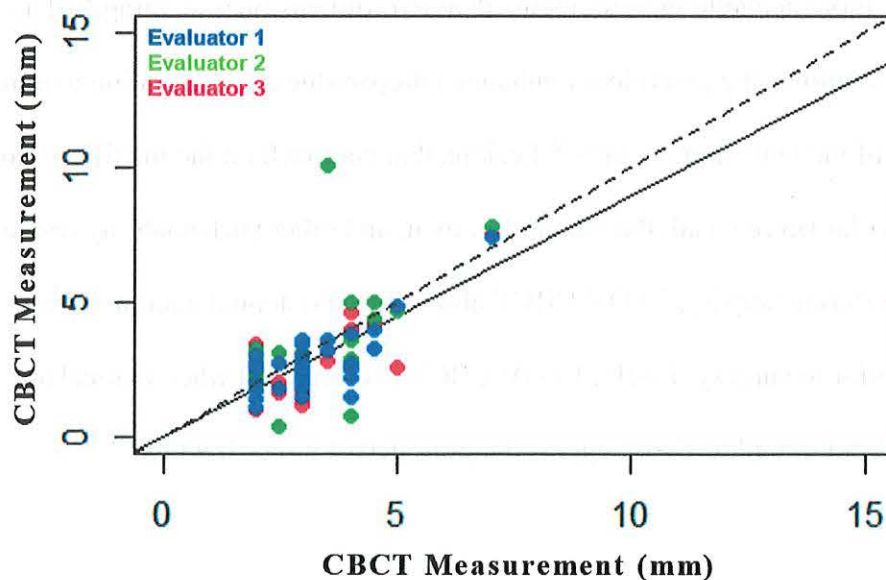
FIGURE 5: LINEAR REGRESSION MODELS FOR LESION SIZE AND BUCCAL BONE PERFORATION SIZE



The different colored dots represent the different measurements for each evaluator while the black dots represent the average of all three evaluators for a given measurement. As a reference, the dashed line represents perfect agreement between the clinical and CBCT measurements; while the solid line represents the linear regression drawn from the evaluators' interpretations. These results suggest that CBCT tends to underestimate the actual area of buccal bone perforations. The evaluators had an intraclass correlation coefficient, or ICC, of 0.61; which indicated moderate agreement. Lesion volumes were calculated in a similar manner and also demonstrated that CBCT tended to underestimate the actual size of lesions, with an ICC of 0.72 indicating moderate to high agreement.

For marginal bone height, no significant difference was noted between the clinical and CBCT measurements. A linear regression model for marginal bone height (FIGURE 6) demonstrated the agreement between the CBCT measurements and the clinical measurements with an ICC of 0.58, indicating moderate agreement.

FIGURE 6: LINEAR REGRESSION MODEL FOR MARGINAL BONE HEIGHT
Marginal Bone Height



For detection of root fractures, the sensitivity was determined to be 0%, indicating evaluators could not detect root fractures when one was clinically present. However, a high specificity was noted at 100%, which represented the ability to detect the absence of a root fracture. A kappa score of 0 indicated no agreement among evaluators.

Only 2 clinical cases presented with communication with other structures, one involving the maxillary sinus and one involving the inferior alveolar nerve canal. There were 6 cases where at least one evaluator interpreted a communication with another anatomic structure when one was not present clinically. For the sake of this interim analysis, these data points were not analyzed with the hope that similar cases will present and allow for better analysis as the study continues to enroll subjects.

IV. DISCUSSION

Endodontic surgery requires an appreciation of regional anatomy to avoid adverse outcomes, such as damage to adjacent teeth and other vital structures. To aid in treatment planning, LFOV CBCT is often utilized to visualize the surgical site in three dimensions and provide more accurate measurements than two-dimensional imaging.^{1,2} The imaging modality also allows the practitioner enhanced preparedness by providing a more in-depth view of the bony architecture.²⁶ Lesions that encroach on the maxillary sinus, the inferior alveolar nerve canal, the mental foramen, and other such anatomy can become problematic during surgery. LFOV CBCT allows these potential encroachments to be visualized prior to surgery. Lastly, LFOV CBCT is often used when clinical and two-dimensional radiographic signs suggest the presence of a root fracture.²⁷

All of the factors listed above were observed in this study; more specifically, the presence or absence of buccal bone perforations and their size, apical lesion size, marginal bone height, the presence or absence of root fractures, and communication with adjacent anatomical structures (such as the maxillary sinus or inferior alveolar nerve canal).

The findings in this study compared favorably with the findings of Haas et al., in that CBCT was accurate when measuring marginal bone height.²⁴ The ability of LFOV CBCT to identify a root fracture was low. This is in agreement with Chavda et al. who also found significant limitations in LFOV CBCT's ability to detect root fractures.²⁵ However, this study found that LFOV CBCT underestimated the actual size of bony defects. This is in contrast with the findings of Liang et al.⁷ who found a high reliability of CBCT-based volumetric measurements, and Misch et al.¹⁹ who found that CBCT tended to over-estimate the amount of alveolar bone present. With regard to the consistency of the raters in this study, the ICCs ranged from 0.58 to 0.72; while the kappa scores ranged from 0 to 0.89. This indicates that experience and caution are necessary when interpreting LFOV CBCT scans and making clinical decisions.

LFOV CBCT also has inherent limitations that must be considered. This includes artifacts, which can obscure portions of the image and make analysis difficult or impossible; and parallax which causes objects to appear different when viewed from different angles. The effects of parallax were minimized in the calibration process by ensuring that each evaluator was viewing the respective object in the same plane. Partial volume averaging must also be considered as its effects can lead to misrepresentation of hard tissue such as periodontal bone support.^{4,21} Misinterpretation of LFOV CBCT, in

this regard, may lead the practitioner to think a given tooth lacks sufficient bone support and unnecessarily give the tooth an unfavorable prognosis. Understanding LFOV CBCT's limitations may help preserve teeth that may otherwise be extracted.

In this study, LFOV CBCT was able to accurately detect the presence or absence of buccal bone perforations. This is of particular worth to the endodontist during root-end surgical procedures, as locating the end of the root may prove challenging if buccal bone is intact. LFOV CBCT offers the surgeon greater foresight in cases like these and helps preserve bone and tooth structure that may otherwise be unnecessarily removed.

V. CONCLUSIONS

The presence or absence of buccal bone perforations was accurately assessed by the LFOV CBCT evaluators in this study, however, their interpretations demonstrated that LFOV CBCT misrepresented the amount of bone in a number of diagnostic situations by underestimating the actual amount of bone present. The imaging modality was also unable to detect the presence of root fractures. Based on these inconsistencies, CBCT should only be used as an adjunct to clinical findings when treatment planning for endodontic surgery. In summary, limited field of view cone beam computed tomography should not be considered the "gold standard" as this could lead to faulty diagnosis and prognosis, but understanding its limitations can help providers better understand the surgical field prior to surgery.

REFERENCES

1. Scarfe WC, Farman AG. What is Cone-Beam CT and How Does it Work? *Dent Clin N Am* 2008;52:707-30.
2. Patel S. New dimensions in endodontic imaging: Part 2. Cone beam computed tomography. *Int Endod J* 2009;42:463-75.
3. Phillips JL, Weller RN, Kulild JC. The Mental Foramen: Part II. Radiographic Position in Relation to the Mandibular Second Premolar. *J Endod* 1992;18:271-4.
4. Molen AD. Considerations in the use of cone-beam computed tomography for buccal bone measurements. *Am J Orthod Dentofacial Orthop* 2010;137:S130-5.
5. Patel S, Dawood A, Mannocci F, Wilson R, Pitt Ford T. Detection of periapical bone defects in human jaws using cone beam computed tomography and intraoral radiography. *Int Endod J* 2009;42:507-15.
6. Kamburoglu K, Kilic C, Ozen T, Horasan S. Accuracy of chemically created periapical lesion measurements using limited cone beam computed tomography. *Dentomaxillofac Rad* 2010;39:95-9.
7. Liang YH, Jiang L, Gao XJ, Shemesh H, Wesselink PR, Wu MK. Detection and measurement of artificial periapical lesions by cone-beam computed tomography. *Int Endod J* 2014;47:332-8.
8. Ahlowalia MS, Patel S, Anwar HMS, Cama G, Austin RS, Wilson R, Mannocci F. Accuracy of CBCT for volumetric measurement of simulated periapical lesions. *Int Endod J* 2013;46:538-46.
9. Esposito SA, Huybrechts B, Slagmolen P, Cotti E, Coucke W, Pauwels R, Lambrechts P, Jacobs R. A novel method to estimate the volume of bone defects using cone-beam computed tomography: an in vitro study. *J Endod* 2013;39:1111-5.
10. de Paula-Silva FWG, Wu MK, Leonardo MR, da Silva LAB, Wesselink PR. Accuracy of periapical radiography and cone-beam computed tomography scans in diagnosing apical periodontitis using histopathological findings as a gold standard. *J Endod* 2009;35:1009-12.
11. Tsai P, Torabinejad M, Rice D, Azevedo B. Accuracy of cone-beam computed tomography and periapical radiography in detecting small periapical lesions. *J Endod* 2012;38:965-70.s
12. Howe RB. First molar radicular bone near the maxillary sinus: a comparison of CBCT analysis and gross anatomic dissection for small bony measurement. *Oral caSurg Oral Med Oral Pathol Oral Radiol Endod* 2009; 108:264-9.
13. Kim TS, Caruso JM, Christensen H, Torabinejad M. A comparison of cone-beam computed tomography and direct measurement in the examination of the mandibular canal and adjacent structures. *J Endod* 2010;36:1191-4.
14. Adibi S, Paknahad M. Comparison of cone-beam computed tomography and osteometric examination in preoperative assessment of the proximity of the

- mandibular canal to the apices of the teeth. *Br J Oral Maxillofac Surg* 2017;55:246-50.
15. Moshfeghi M, Tavakoli MA, Hosseini ET, et al.. Analysis of linear measurement accuracy obtained by cone beam computed tomography (CBCT-NewTomVG). *Dent Res J* 2012;9:S57-62.
 16. Al-Ekrish A, Ekram M. A comparative study of the accuracy and reliability of multidetector computed tomography and cone beam computed tomography in the assessment of dental implant site dimensions. *Dentomaxillofac Rad* 2011;40:67-75.
 17. Timock AM, Cook V, McDonald T, et al.. Accuracy and reliability of buccal bone height and thickness measurements from cone-beam computed tomography imaging. *Am J Orthod Dentofacial Orthop* 2011;140:734-44.
 18. Wood R, Sun Z, Chaudhry J, et al.. Factors affecting the accuracy of buccal alveolar bone height measurements from cone-beam computed tomography images. *Am J Orthod Dentofacial Orthop* 2013;143:353-63.
 19. Misch KA, Yi ES, Sarment DP. Accuracy of Cone Beam Computed Tomography for Periodontal defect Measurements. *J Periodontol* 2006;77:1261-6.
 20. Leung CC, Palomo L, Griffith R, et al.. Accuracy and reliability of cone-beam computed tomography for measuring alveolar bone height and detecting bony dehiscences and fenestrations. *Am J Orthod Dentofacial Orthop* 2010;137:S109-19.
 21. Sun Z, Smith T, Kortam S, et al.. Effect of bone thickness on alveolar bone-height measurements from cone-beam computed tomography images. *Am J Orthod Dentofacial Orthop* 2011;139:e117-e127.
 22. Behnia H, Motamedian SR, Kiani MT, Morad G, Khojasteh A. Accuracy and reliability of cone beam computed tomographic measurements of the bone labial and palatal to the maxillary anterior teeth. *Int J Oral Maxillofac Implants* 2015;30:1249-55.
 23. Banodkar AB, Gaikwad RP, Gunjekar TU, Lobo TA. Evaluation of accuracy of cone beam computed tomography for measurement of periodontal defects: a clinical study. *J. Indian Soc. Periodontol* 2015;19:285-9.
 24. Haas LF, Zimmermann GS, De Luca Canto G, Flores-Mir C, Correa M. Precision of cone beam CT to assess periodontal bone defects: a systematic review and meta-analysis. *Dentomaxillofac Rad* 2017;90:S1-16.
 25. Chavda R, Mannocci F, Andiappan M, et al.. Comparing the *In Vivo* Diagnostic Accuracy of Digital Periapical Radiography with Cone-beam Computed Tomography for the Detection of Vertical Root Fracture. *J Endod* 2014;40:1524-9.

26. Low KM, Dula K, Burgin 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.
27. Fayad MI, Ashkenaz PJ, Johnson BR. Different Representations of Vertical Root Fractures Detected by Cone-Beam Volumetric Tomography: A Case Series Report. *J Endod* 2012;38:1435-42.

