

A CLINICAL EVALUATION OF CONE BEAM COMPUTED TOMOGRAPHY

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Master of Science  
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CERTIFICATE OF APPROVAL

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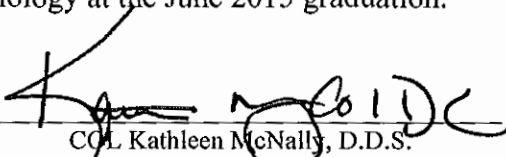
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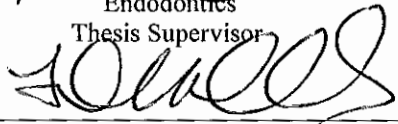
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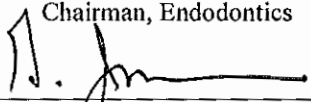
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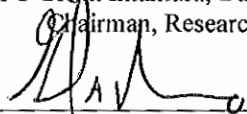
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NAVAL POSTGRADUATE DENTAL SCHOOL  
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2015

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## ABSTRACT

### A CLINICAL EVALUATION OF CONE BEAM COMPUTED TOMOGRAPHY

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D.D.S., ENDODONTICS, 2015

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**INTRODUCTION:** Limited field of view (FOV) cone beam computed tomography (CBCT) imaging is a valuable adjunct in pre-surgical assessment. The literature contains a broad spectrum of analysis concerning the cone beam's capabilities and limitations. To date there is limited information documenting discrepancies between CBCT images and clinical presentation. The purpose of this prospective in vivo study is to compare the data gathered from pre-surgical CBCT images to data from endodontic surgeries. **METHOD:** Patients requiring endodontic surgery and warranting CBCT imaging at the Naval Postgraduate Dental School were enrolled in this IRB approved study. Standardized questions were answered during the surgical treatment and photographs documented the clinical findings. Pre-surgical CBCT images were obtained using the Carestream, limited FOV, CBCT and evaluated separately by 3 calibrated, board certified specialists. Descriptive data from the surgical procedures and the CBCT images were evaluated. **RESULTS:** A total of 12 teeth were evaluated. Data were available to report on: linear bone height, buccal bone perforation, sinus communication and root fracture. Marginal bone height was overestimated an average of 0.9mm on CBCT images. Analysis revealed 88% accuracy in identification of buccal plate perforations on CBCT images. Communication between an apical lesion and the maxillary sinus was correctly identified in 94% of the images. CBCT evaluation had 93% specificity and 50% sensitivity in the ability to detect a root fracture. **CONCLUSION:** The limited FOV CBCT accurately detected bony communications; however, the presence of bone was overestimated. When a vertical root fracture was present, the CBCT provided limited diagnostic value in detecting the actual root fracture. Based on these discrepancies, the limited FOV CBCT should be used as a radiographic adjunct and should not be considered a true representation of clinical presentation.

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## LIST OF ABBREVIATIONS

|             |                                                             |
|-------------|-------------------------------------------------------------|
| AAE.....    | American Association of Endodontists                        |
| AAOMR.....  | American Association of Oral and Maxillofacial Radiologists |
| ALARA.....  | As Low As Reasonably Achievable                             |
| CBCT.....   | cone beam computed tomography                               |
| CEJ.....    | cementoenamel junction                                      |
| CT.....     | computerized tomography                                     |
| FDA.....    | Food and Drug Administration                                |
| FOV.....    | field of view                                               |
| IA.....     | inferior alveolar                                           |
| IRB.....    | Institutional Review Board                                  |
| kVp.....    | kilovolt peak                                               |
| mA.....     | milliamp                                                    |
| mm.....     | millimeter                                                  |
| PA.....     | periapical                                                  |
| PC.....     | personal computer                                           |
| S/N.....    | signal to noise ratio                                       |
| VRF.....    | vertical root fracture                                      |
| WRNMMC..... | Walter Reed National Military Medical Center                |
| 2D.....     | two dimensional                                             |
| 3D.....     | three dimensional                                           |

## **Chapter I: Introduction**

Accurate diagnostic imaging is critical in the assessment of the patients. Kells first discovered this in 1899 when he visualized a lead wire in a root canal using “radiogram” to establish root canal treatment working length. Since then radiography has proven to be a key tool in the practice of endodontics (Scarfe, Levin, Gane, & Farman, 2009). Radiography allows clinicians to visualize hard tissue morphology and pathologic alterations. It provides information on tooth shape, the location and number of canals, the size of the pulp chamber and degree of calcification, root structure, direction and curvature, the presence of root fractures or iatrogenic defects and the extent of dental caries.

The radiographic image is essential to successfully diagnose pathosis of odontogenic and non-odontogenic origin. The effects of periradicular disease can be detected using the periapical (PA) radiograph. They are helpful during pre-surgical evaluations, in predicting complications prior to initiating care and highlighting potential obstacles to re-treatment. The intraoperative PA radiograph is used extensively during treatment to aid in establishing working length and positioning obturation materials prior to final placement (Scarfe et al, 2009). Postoperative PA radiographs are used to critically assess the final obturation and serve as a baseline to evaluate therapy and healing. The outcome of endodontic treatment is frequently evaluated by comparing a series of PA images exposed at different points in time. Reduced radiolucency combined with clinical normalcy can be interpreted as progressive healing (Friedman, 2002).

Historically PA films have served as the primary diagnostic image for endodontic surgery (Ludlow & Ivanovic, 2008). Because these images are two-dimensional (2D) representations of a three dimensional (3D) object, a series of angled PA's are required to accurately localize

structures *in situ*. In the 1960's the panoramic image was introduced and offered a comprehensive view of maxillofacial structures (Scarfe, Farman, & Sukovic, 2006). Panoramic images however suffered from distortion, superimposition and misrepresentation of structures (Phillips, Weller, & Kulild, 1992).

Numerous efforts have been directed toward generating a 3D image for oral structures. Although computed tomography (CT) imaging has been available to dentistry, its use has been limited due to the cost, patient access, radiation dose concerns, and the relatively low resolution (Scarfe et al, 2006; Ngan, Kharbanda, Geenty, & Darendeliler, 2003). Cone Beam Computed Tomography (CBCT) was developed in the 1980's for use in angiography. More recent medical uses have included applications in radiotherapy guidance and mammography (Scarfe & Farman, 2008). In the late 1990's computers with sufficient computational complexity and x-ray tubes capable of continuous exposure became available. These advances allowed the manufacture of small and inexpensive systems for use in dentistry (Scarfe & Farman, 2008). CBCT scanners take up about the same space as panoramic radiographic machines (Scarfe et al, 2006).

CBCT has revolutionized oral and maxillofacial imaging. It represents a shift from a 2 dimensional to a 3 dimensional approach in data acquisition and image reconstruction. As a result, the role of imaging has expanded from the diagnosis and treatment to image guidance by way of third party application software (Scarfe & Farman, 2008). CBCT has been reported to have more clarity than computed axial tomography (CAT scan) when viewing maxillofacial structures. It provides views from three orthogonal planes (coronal, sagittal, and axial) and has image quality preferred to CT in assessing dental hard tissues (Hashimoto et al, 2003). The high resolution of the CBCT was preferred in detecting small hard tissue structures such as canals carrying neurovascular bundles when compared to a multi-sliced CT scanner (Bartling et al,

2007). Schulze reported the average radiation effective dose of CBCT is within 36.9 and 50.3 micro Sieverts, which is approaching a 98 percent reduction compared to a fan-beam CT system (Schulze, Heiland, Thurmann, & Adam, 2004). The reduction of radiation can be attributed to rapid scan times, pulsed X-ray beams and sophisticated image receptor sensors. However, the primary advantage of this technology is the 3D rendered image (Cotton, Geisler, Holden, Schwartz, & Schindler, 2007). This linked, interactive image, allows clinicians to pinpoint a specific site and move in unison to visualize the site in all planes giving practitioners the most precise information on a specific anatomic structure, the dimensions of a lesion or of lesions, and quantity of remaining hard tissue. CBCT images have become an invaluable tool in pre-surgical preparation and treatment planning.

## **Importance in Surgery**

The limitations of conventional films are of particular relevance during surgical treatment planning. The missing 'third dimension' in PA's and panoramic radiographs becomes readily apparent when attempting to determine the angulation of a root to the cortical plate or ascertain the thickness of remaining cortical bone. Relationships of the root to key adjacent anatomical structures such as the inferior alveolar nerve, mental foramen or maxillary sinus are identified in many slices of the CBCT (Velvart, Hecker, & Tillinger, 2001). The mental foramen is an important anatomic landmark for various dental surgical procedures; it is valuable to have information on its size and position. Although many studies have been conducted using cadavers, periapical radiographs, and panoramic radiographs, CBCT technology has been shown to be the most advantageous modality for this purpose (Aminoshariae, Su, and Kulild, 2014). CBCT

volumes seem to be a reliable way to determine the size and location of the mental foramen. This could greatly aid a clinician in preparation before surgery to minimize iatrogenic trauma to the nearby neurovascular structures (Carruth, He, Benson, and Schneiderman, 2015). Rigolone and others concluded that CBCT might play an important role in planning for periapical microsurgery on palatal roots of maxillary first molars by establishing the distance between the cortical plate and the palatal root apex and the presence or absence of the maxillary sinus between the roots (Rigolone et al, 2003). The thickness of cortical plate, cancellous bone patterns, fenestrations, as well as root inclinations of teeth can be accurately determined preoperatively by selecting relevant views and slices of data (Nakata et al, 2006). Root morphology and bony topography is better visualized in three-dimensions, as are the number of root canals and their relationship to each other. Axial slices may reveal root canals missed or untreated in PA radiographs (Low, Dula, Burgin, & von Arx, 2008). Viewing the CBCT prior to surgery can aid in establishing the size, location and extent of a periapical lesion. Lowe and others compared PA and CBCT images in endodontically treated maxillary posterior teeth being assessed for periapical surgery. This study found 34% of the periapical lesions detected by CBCT were missed on PA radiographs, and the likelihood of discovery on a 2D image was further reduced when the root apices were in close proximity to the floor of the maxillary sinus. This was especially true when there was less than 1 mm of bone remaining between the periapical lesion and the sinus floor (Lowe et al, 2008). Utilizing CBCT data, a true scale model (rapid prototype anatomical model) can replicate the area of interest. This production supports the ability to produce three-dimensional rendered images allowing surgeons to familiarize themselves with the potential surgical site prior to the procedure and confidently plan their surgical approach (Scarfe et al, 2006).

The Food and Drug Administration (FDA) approved the first CBCT unit for dental use in the United States in 2001 - The New Tom DVT 900 (Quantitative Radiology srl, Verona, Italy). Since 2001, a number of other CBCT units have received FDA approval (Scarfe et al, 2009). These devices employ the same controls found in conventional dental radiography units. A cathode ray tube containing a tungsten filament is energized to generate photons within the x-ray region of the light spectrum. Increasing the tube current (mA) increases photon production. Increasing the potential across the tube (kVp) also increases the number of photons but more importantly increases their energy. Changing the time controls the duration of the exposure (Ballrick, Palomo, Ruch, Amberman, & Hans, 2008).

CBCT technology employs a cone-shaped beam of radiation to capture images. This beam design covers a larger area and produces images faster, using less radiation than a traditional medical CT scanner (Scarfe & Farman, 2008). The volume of data acquired is composed of a three-dimensional pixel or voxel. Because the data is acquired in a volumetric format, voxels are isotropic, or cube shaped. (Fig. 1.)

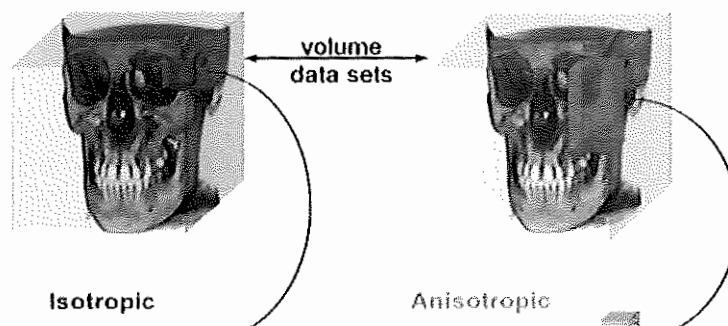


Figure 1. CBCT volume sets are isotropic voxels equal in all three dimensions, rather than columnar voxels which unequal the height and width (Scarfe & Farman, 2008).

CT images are acquired in slices resulting in rectangular voxels, which are incapable of accurate measurements made in multiple planes (Cotton et al, 2007). CBCT differs from CAT scan imaging in that the entire three-dimensional volume of data is acquired in the course of a single sweep of the scanner. The X-ray beam captures a cylindrical or spherical volume of data, described as the field of view (Patel, 2009).

The CBCT captures a sequential series (150 to 600 images) of 2D digital “basis images” as the X-ray source and detector rotate around the patient’s head (Scarfe & Farman, 2008). Imaging usually requires a full 360° rotation around the subject forming a center of rotation. “Volume imaging”, refers to the cylindrical region formed around this rotation center where the full series of basis images overlap (Fig. 2.). It contains the most complete and accurate tissue density data and should include the area of interest. The image is then reconstructed using a mathematical transformation to generate a 3-D rendered image (Scarfe et al, 2009).

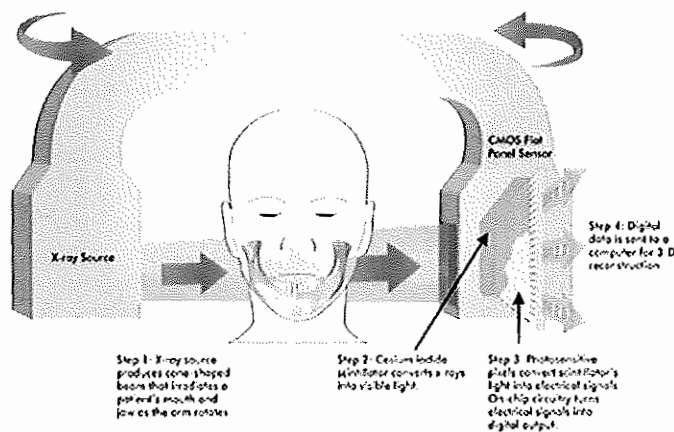


Figure 2. Volume Imaging (Hans, 2011)

Voxels range in size from 0.076 mm-0.40 mm (Olubamiji, 2011). These dimensions represent thickness of the CBCT slice. Additionally, the isotropic nature of CBCT voxels allow for the reconstruction of images in non-orthogonal planes, e.g. rendering the captured data in other formats such as a conventional 2-D panoramic film.

The volume data captured by the CBCT is described as the field of view (FOV). The size of the FOV varies and is established by the scanner. Large FOV scanners are capable of capturing the entire maxillofacial skeleton with the resulting image ranging in height from 100-200mm. Other machines allow the height of the (cylindrical) FOV to be adjusted to capture only the maxilla or mandible (Cotton et al, 2007). These are reduced to ranges in height of 40-100mm. Limiting the FOV has the advantage of reducing patient radiation exposure (Patel, 2009). Limited FOV machines also use smaller voxels when compared to large FOV units (Olubamiji, 2011). According to the AAE Colleagues for Excellence, 2011 *Cone Beam-Computed Tomography in Endodontics*, limited FOV CBCTs are more suited for endodontic applications for the following reasons: “1. increased resolution to improve diagnostic accuracy for endodontic-specific tasks such as the visualization of small features, calcified/accessory canals, etc., 2. highest possible resolution, 3. decreased radiation exposure to the patient, 4. time savings due to smaller volume to be interpreted, 5. smaller area of responsibility, 6. a focus on anatomical area of interest.”

ALARA (As Low As Reasonably Achievable) remains the fundamental principle of diagnostic radiology. Dose minimization can be achieved by:

1. Application of appropriate radiograph selection criteria after taking a history from the patient, followed by clinical evaluation by an appropriate health care professional

2. Employment of properly trained and credentialed personnel to make radiographic exposures upon the prescription of a licensed health care professional
3. Application of optimal technique factors including; beam projection geometry, beam energy, collimation and filtration
4. Use of the fastest x-ray detector consistent with obtaining a radiographic image of adequate diagnostic quality (Farman & Farman, 2005)

Clinicians should only employ CBCT when the need for imaging cannot be adequately satisfied by lower dose conventional dental radiography or alternate imaging modalities (AAE Colleagues for Excellence, 2011). According to the American Association of Endodontists (AAE) position statement, the following recommendations for the use of CBCT in endodontics should be limited to the assessment and treatment of complex endodontic conditions such as:

- Identification of potential accessory canals in teeth with suspected complex morphology based on conventional imaging
- Identification of root canal system anomalies and determination of root curvature
- Diagnosis of dental periapical pathosis in patients who present with contradictory or nonspecific clinical signs and symptoms, who have poorly localized symptoms associated with an untreated or previously endodontically treated tooth with no evidence of pathosis identified by conventional imaging, and in cases where anatomic superimposition of roots or areas of the maxillofacial skeleton is required to perform task-specific procedures
- Diagnosis of non-endodontic origin pathosis in order to determine the extent of the lesion and its effect on surrounding structures

- Intra- or post-operative assessment of endodontic treatment complications, such as overextended root canal obturation material, fractured endodontic instruments, calcified canal identification, and localization of perforations
- Diagnosis and management of dento-alveolar trauma, especially root fractures, luxation and/or displacement of teeth, and alveolar fractures
- Localization and differentiation of external from internal root resorption or invasive cervical resorption from other conditions, and the determination of appropriate treatment and prognosis
- Pre-surgical case planning to determine the exact location of root apex/apices and to evaluate the proximity of adjacent anatomical structures
- Dental implant case planning when cross-sectional imaging is deemed essential based on the clinical evaluation of the edentulous ridge (AAE CBCT position statement, 2011)

## **Limitations of CBCT**

Despite providing visualization of the third dimension, the spatial resolution of CBCT images (0.4 mm to 0.076 mm or equivalent to 1.25 to 6.5 line pairs per mm<sup>-1</sup>[lp.mm<sup>-1</sup>]) is inferior to conventional film-based (approx. 20 lp.mm<sup>-1</sup>) or digital (ranging from 8–20 lp.mm<sup>-1</sup>) intraoral radiography. However, the human eye can only perceive approximately 10 line pairs per mm<sup>-1</sup> (A. Farman, T. Farman, 2005; Yamamoto, Ueno, Seo, & Shinohara, 2003). Therefore, digital dental radiography resolution has surpassed our visual threshold, whereas CBCT imaging has the capacity to improve.

Image artifacts are any distortions or inaccuracies not related to the object (Scarfe & Farman, 2008). Cone beam artifacts are attributed to the shape of the beam utilized and/or the mathematical algorithm used in image reconstruction and fall into 3 major categories:

1. The “partial volume effect” occurs when scanned voxels include areas of differing, non-homogenous, densities. Because the information is digital, the reconstruction algorithm will calculate a weighted average for the voxel. The captured voxels therefore will not accurately represent the corresponding object area in the 3D rendered image. If displayed, non-homogenous voxels may present as a stair step boundary in the image (Ballrick, Palomo, Ruch, Amberman, & Hans, 2008).
2. “Under sampling” occurs when an insufficient number of basis images are included in the reconstructed image. These images lack sharp edge detail (Scarfe & Farman, 2008).
3. The “cone beam effect” is caused by beam divergence as it moves away from the source. The cylindrical region, the area where the basis images have the greatest overlap, contains the most accurate data. Areas superior and inferior to this have incomplete data, which generates noise leading to image distortion and reduced contrast. The cone beam effect manifests as a “V” shaped artifact on the top and bottom of images (Scarfe & Farman, 2008). (Fig. 3)

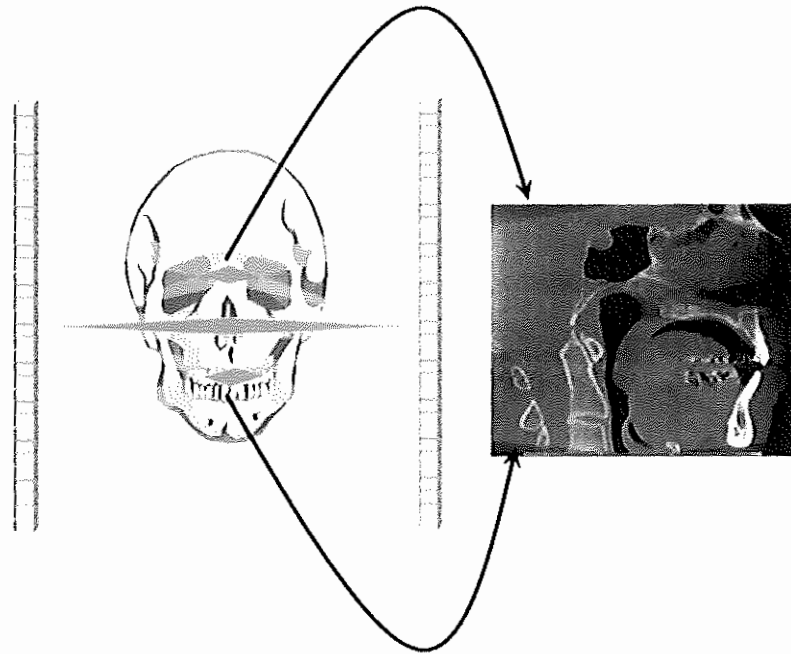


Figure 3. Origin of the cone-beam effect. The projection of three x-ray beams (one perpendicular, one angled inferiorly, and the other angled superiorly) from a point origin are shown at two positions of the x-ray tube, 180 degrees apart. The amount of data collected by the detector for reconstruction corresponds to the solid volume between the overlapping projections. Centrally, the amount of data acquired is maximal, whereas peripherally, the amount of data collected is appreciably less. The midsagittal section image demonstrates the visual effects of this in producing a peripheral “V” artifact of increased noise, distortion, and reduced contrast. (Scarfe & Farman, 2008)

“Noise”, the principle detriment to CBCT contrast resolution (Miracle & Mukherji, 2009), results from the generation of spurious signals. Noise degrades image quality by decreasing the signal to noise (S/N) ratio and appears to the viewer as “snow”. It is primarily caused by non-linear photon attenuation (Compton scattering) as the lower energy photons scatter omni-directionally. If captured by the detector, they do not represent a true amount of photon attenuation.

Scatter and beam hardening is a significant problem affecting CBCT image quality and diagnostic accuracy (Fig. 4). It is caused by high density neighboring structures, such as enamel, metal posts and restorations (Mora, et al. 2007). Crowns, bridges, implants, fillings, and intracanal posts can mimic endodontic complications or hide the existing ones (Venskutonis et

al. 2014). If this scattering and beam hardening is associated close to or with the tooth being assessed, the resulting CBCT images may be of minimal diagnostic value (Lofthag-Hansen, Huuonen, Grondahl K, & Grondahl H, 2007).

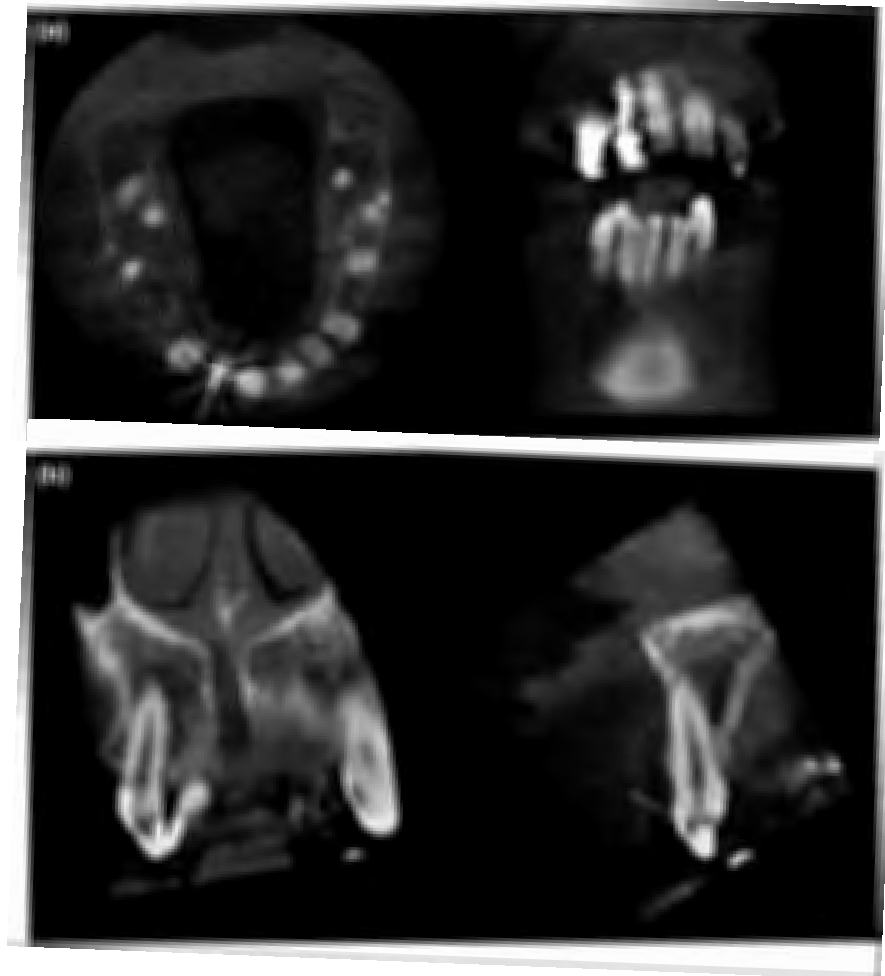


Figure 4. (a) Scatter and beam hardening around metallic restorations may result in a reduction in the quality of reconstructed CBCT images. (b) These reconstructed coronal and sagittal images of another case appear to show radiolucencies in the maxillary right lateral incisor, which may be mistaken for caries (yellow arrow)-this is actually scatter caused by overlying enamel and direct composite restoration in the tooth. (Patel, 2009)

CBCT is not sufficient for soft tissue evaluation. If the sole purpose area of interest were hard tissue, CBCT would be a viable option, as it does not sufficiently capture soft tissue entity. Although limitations currently exist in the use of this technology for soft tissue imaging, efforts are being directed toward the development of techniques and software algorithms to improve signal-to-noise ratio and increase contrast (Scarfe & Farman, 2008).

Finally, the scan times are 5–20 seconds, which require patients to remain absolutely still. Patient motion can cause unsharpness in the reconstructed image. This unsharpness can be minimized by using a head restraint and as short a scan time as possible (Scarfe & Farman, 2008).

## **Chapter II: Review of Literature**

The literature contains a broad spectrum of analysis of the cone beam's capabilities and limitations. While some advocate that cone beam CT's should be used as the gold standard; most agree it is valuable, but limited when utilized for diagnosis and treatment planning. Several studies suggest that cone beam images are highly accurate. Ballrick and others stated that linear measurements from cone beam CT images were within 0.1mm when using an in vitro phantom model (Ballrick, Palomo, Ruch, Amberman, & Hans, 2008). Cadaver studies demonstrated the CBCT's ability to quantitatively assess buccal bone height and buccal bone thickness with high precision and accuracy (Timock et al, 2011). Hilgers et al found no statistical significance between the measurements from the CBCT images and the anatomical truth (Hilgers, Scarfe, Scheetz, & Farman, 2005). Moshfegi and others reported cone beam to be highly accurate and reproducible in linear measurements in axial and coronal images (Moshfegi, Tavakoli, Hosseine, & Hosseine, 2012).

Other studies concluded that cone beam CT's were accurate, but limited. Misch and others reported that although there was a tendency for the CBCT to be more accurate than probing or conventional radiography for measuring bone height, cone beam overestimated the amount of bone by an average of 29% (Misch et al, 2006). Al-Ekrish and others noted cone beam CT's were more accurate than medical CT's, but still had an average error of 0.5mm (Al-Ekrish & Ekram, 2011).

Finally, other studies have reported cone beam CT's to be inaccurate. Leung and others noted cone beam underestimated buccal bone by incorrectly identifying 3 times as many

fenestrations that were present. Areas of bone less than 0.6 mm thick were invisible (Leung, Palomo, Griffith, & Hans, 2010). For these reasons, bone may not be accurately represented in cone beam CT images. Sun and others reported when bone is thicker than the voxel size, it is over-reported, however, when the cortical plate was thin, it approached the voxel size, and was underreported.

Anecdotal reporting by endodontists performing surgery has found discrepancies in the quantity of bone *in situ* than was depicted on pre-surgical CBCT images. Unexpected complications such as these add additional time to a procedure. Studies have demonstrated that although reliable, CBCT measurements tend to underestimate bone thickness and height (Baumgartel, Palomo J, Palomo, & Hans, 2009). Ballrick et al noted that a minimum distance of 0.86 mm is required between two objects of the same density. Alveolar bone is separated from cementum by a periodontal ligament space approximately 0.5mm thick, which is smaller than this minimum dimension requirement. This suggests that alveolar bone is likely to be indistinguishable from cementum.

Cone beam computed tomography represents an improvement over previous dental imaging modalities. However, these instruments have limitations. Clinicians should have an understanding of their correct operation of the instrument and associated imaging software in order to properly adjust and interpret images. The purpose of this prospective in vivo study was to compare data evaluated from limited field of view cone beam CT images to data collected during endodontic surgical procedures.

## **Chapter III: Materials and Methods**

This prospective, in vivo study was approved by the Walter Reed National Military Medical Center (WRNMMC) Institutional Review Board (IRB). The inclusion criteria were: 1.) That endodontic surgery was indicated. 2.) The patients were at least 18 years old and able to consent. 3.) A limited field of view cone beam was indicated for the procedure and captured using the Carestream 9000 or 9300. All CBCT images were taken independent of the study and in accordance with the 2010 American Association of Endodontists (AAE) and the American Association of Oral and Maxillofacial Radiologists (AAOMR) Joint Position Statement. All surgeries were performed at the Naval Postgraduate Dental School.

During the surgical phase, a contemporary root end surgical procedure was completed as indicated. Surgical providers recorded clinical information based on standardized research questions (Appendix A), and photographs were taken to document the clinical information. The Cone Beam evaluation was performed by 3 calibrated board certified specialists; 1 Oral & Maxillofacial Radiologist and 2 Endodontists. Each evaluator viewed the scans separately on the same laptop using the recommended viewing software. Standardized research questions were answered based on the evaluators radiographic interpretation of the scans. (Appendix B)

The CBCT images were uploaded onto a Dell Inspiron 15.6" laptop PC (Dell Computer Corporation, Round Rock, TX). Each evaluator viewed the scans separately on the same laptop using the recommended Carestream viewing software. The reviewers had access to all the features available in this software and could observe multi-planar reconstructed images (axial,

coronal, and sagittal) as well as parasagittal and circumferential images. The evaluators were given unlimited time to view the images.

CBCT images were evaluated in 4 areas of clinical relevance by the investigators. These included; remaining vertical bone height, presence of bone detected (perforation of cortical plate), communication between a lesion and the maxillary sinus or other structures, and root fracture. Surgical providers recorded clinical information based on standardized research questions, and photographs were taken to document the clinical information. Data was collected using the form (Appendix B).

In most cases this consisted of a photograph and treatment notes. Descriptive data were analyzed by comparing clinical data, obtained during the surgical procedure, to the CBCT radiographic information from the 3 evaluators.

## Chapter IV: Results

A total of 13 teeth were evaluated, one was excluded due to poor diagnostic quality of the Cone Beam scan. There were 10 maxillary and 2 mandibular teeth, of which 7 were anterior and 5 were posterior. No mandibular anterior cases were evaluated. (Table 1)

Table 1. Tooth distribution

|                   | <b>Anterior</b> | <b>Posterior</b> |
|-------------------|-----------------|------------------|
| <b>Maxillary</b>  | <b>7</b>        | <b>3</b>         |
| <b>Mandibular</b> | <b>0</b>        | <b>2</b>         |

Data were available to report on: linear bone height, buccal bone perforation, sinus communication, and root fracture.

### Linear Bone Measurements

Using the Carestream software-measuring tool, marginal bone height was measured from the cementoenamel junction (CEJ) or crown margin to determine linear bone height as depicted in the cone beam image. (Figure 5)

This measurement was compared to the clinical data gathered during the surgical procedure. The measurement was taken with a periodontal probe place mid-buccal. (Figure 6)



Figure 5. CBCT Coronal view #29

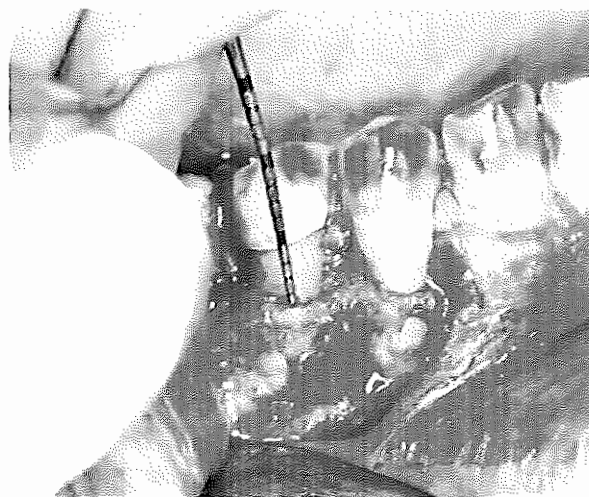


Figure 6. Clinical view #29

When comparing the clinical data with the cone beam measurement, bone was over reported in cone beam CT images in 7 of 9 cases with a mean over estimation of 0.9mm, meaning there was less bone clinically.

### **Buccal Bone Perforation**

Buccal bone perforation is defined as an opening or defect in the alveolar plate of bone. Evaluation revealed 28 of the 33 responses were consistent with clinical findings resulting in an overall accuracy of 88%. The accuracy in cone beam CT perforation detection was the same whether a perforation existed clinically or not. One Endodontist had 100% accuracy in the detection of buccal bone perforations.

## **Sinus Communication**

Communication with the sinus is defined as a perforation of the cortical plate separating the structures. As an example, interpretation of the cone beam image indicated no presence of sinus perforation (Figure 7), which was confirmed in the clinical presentation slide on the right (Figure 8).



Figure 7. CBCT Coronal view #3

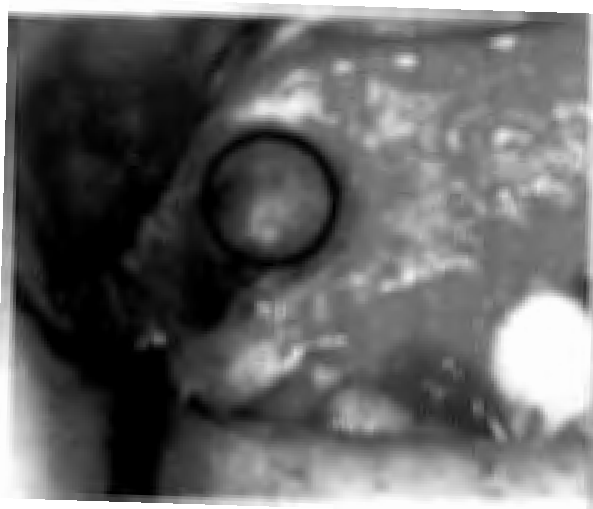


Figure 8. Clinical view #3

There was a 94% accuracy reported. There were no cases with actual communication clinically present. The Oral and Maxillofacial Radiologist had 100% accuracy in detecting an intact sinus.

## **Root Fracture**

When evaluating for the presence of root fracture, the cone beam evaluation resulted in a

50% sensitivity, which is the ability to detect a fracture when it is actually present. It produced a 93% specificity, which is the ability to detect a tooth that is not fractured. Of the 12 cases evaluated, there were only two cases with root fracture, one horizontal root fracture and one vertical root fracture.

## Chapter V: Discussion

A consistent finding of this study was the overestimation of alveolar bone height with CBCT imaging. This is in agreement with the findings of Lund and others, who reported a trend for cone beam to overestimate alveolar bone height. It was speculated that a major factor might be the ability to correctly identify the cementoenamel junction and crestal bone termination. Artifacts due to restorative materials that contain metallic substrates may have influenced the identification of the CEJ (Lund, et al 2010). However, in some cases bone was underestimated. Sun et al. suggested underestimation was due to the phenomenon of bone becoming invisible on CBCT images. This is likely caused by 2 factors: the partial-volume averaging effect and the limitation of contrast resolution related to CBCT machines. The partial-volume effect occurs when scanned voxels include areas of differing, non-homogenous, densities. These voxels on CBCT images reflect the average density of both objects rather than the true value of either object. A thin layer of bone with a thickness near or below the voxel size of the CBCT image can become indistinguishable (Sun et al, 2011). The accuracy of alveolar bone height measurements from CBCT images depends on multiple factors. Wood et al found that cone beam CT measurements were more accurate in the mandible when compared to the maxilla. This was attributed to the difference in the bone thickness discrepancy between the arches (Wood et al, 2013). Of the cases evaluated in the current study, 83% (10/12) were maxillary, which may influence the accuracy due to the ratio of maxillary to mandibular teeth reviewed. This study reported an average overestimation of less than a millimeter, and may be clinically insignificant.

With regard to buccal bone perforations, the results of this study agree with Leung and others and support the use of cone beam CT for detection of dehiscence and fenestration (Leung,

Palomo, Griffith, & Hans, 2010). In the absence of sinus perforations, this study agrees with the findings of Bornstein and others demonstrating cone beam CT's value to evaluate anatomically demanding areas prior to apical surgery (Bornstein et al, 2012). This study's findings are also in agreement with the observations reported by Neves and others, demonstrating that the presence of obturation and restorative materials negatively impacts the diagnostic capabilities of detecting vertical root fractures in cone beam CT images (Neves et al, 2014). One subject was eliminated due to the poor quality of the cone beam scan.

Incomplete vertical or horizontal root fractures can be difficult to diagnose. A single 2D radiograph is of limited value in the detection of vertical root fracture. With a two dimensional radiograph if the fracture is not in the plane of the beam, the fracture will not be visualized, and may only provide indirect evidence. CBCT can overcome some of the limitations of 2D digital radiography, with the ability to view the tooth from multiple planes and different angles. Fayad et al suggests 5 specific findings on a cone beam CT that may assist in the detection of vertical root fracture: 1. Loss of bone in the mid-root area with intact bone coronal and apical to the defect. 2. Absence of the entire buccal plate of bone in axial, coronal, and/or 3D reconstruction view. 3. Radiolucency around a root where a post terminates. 4. Space between the buccal and/or lingual plate of bone and root surface. 5. Visualization of the vertical root fracture (VRF) on CBCT (Fayad, Ashkenaz, & Johnson, 2012).

The cone beam images were evaluated by 3 calibrated board certified specialist, which included 2 Endodontists and an Oral & Maxillofacial Radiologist. These specialists generally have more experience in evaluating limited field of view cone beam CTs. The results of this interim analysis suggests that practitioners with more experience in interpreting cone beam CTs

are accurate in detecting pathosis such as buccal bone defects, sinus perforations and root fractures. A limitation of this study is the small sample size. An increase in the cases evaluated may alter current findings and be more representative of the accuracy of limited field of view cone beam CT images. Another limitation is that only one software program (Carestream) was used to quantitatively analyze the CBCT images. Other software may differ in image reconstruction, display, and analysis, and potentially affect the accuracy of the interpretation and alveolar bone measurements.

## **Chapter VI: Conclusion**

Based on this interim analysis, the limited FOV cone beam CT accurately detected bony communications, however, the presence of bone was overestimated. When a vertical root fracture was present, the cone beam CT provided limited diagnostic value in detecting the actual root fracture. Based on these discrepancies, the limited field of view cone beam CT should be used as a radiographic adjunct and should not be considered a true representation of clinical presentation.

**Appendix A**

**SURGICAL REVIEW**

REGISTRY PATIENT # \_\_\_\_\_

Surgeon \_\_\_\_\_

Date \_\_\_\_\_

CBCT TAKEN \_\_\_\_\_

TOOTH # \_\_\_\_\_

Vertical bone height \_\_\_\_\_ mm.

Take photo with perio probe \_\_\_\_\_

(Measured from CEJ to crestal bone)

Perforation of cortical plate? Yes / No

Take photo with perio probe \_\_\_\_\_

Measurement: width \_\_\_\_\_ X height \_\_\_\_\_ mm.

Communication with sinus or other

Take photo \_\_\_\_\_

structures? (IA canal, mental foramen, infraorbital canal) Yes / No

\_\_\_\_\_

Dimensions of lesion \_width\_\_\_\_\_ X height\_\_\_\_\_ mm.

Vertical root fracture? Yes / No

Take photo \_\_\_\_\_

Untreated canal(s) located? Yes / No

Take photo \_\_\_\_\_

\_\_\_\_\_ canal

**Other findings**

(fractured instruments, extruded material,

root perforation, ect.)

Take photo \_\_\_\_\_

**Appendix B**

**CBCT REVIEW**

REGISTRY PATIENT # \_\_\_\_\_

Reviewer \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Date \_\_\_\_\_

CBCT TAKEN \_\_\_\_\_

TOOTH # \_\_\_\_\_

Vertical bone height \_\_\_\_\_ mm.

(Measured from CEJ to crestal bone)

Perforation of cortical plate? Yes / No

Measurement: width \_\_\_\_\_ X height \_\_\_\_\_ mm.

Communication with sinus or other

structures? (IA canal, mental foramen, infraorbital canal) Yes / No

\_\_\_\_\_

Dimensions of lesion: width \_\_\_\_\_ X height \_\_\_\_\_ mm.

Vertical root fracture? Yes / No

Untreated canal(s) located? Yes / No

\_\_\_\_\_ canal

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

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