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Evaluation of Maxillary Molar Furcations, Clinical Measurements versus Cone Beam Computed Tomography

Jessica Allen
Virginia Commonwealth University

Evaluation of Maxillary Molar Furcations, Clinical Measurements versus Cone Beam Computed Tomography

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

By

Jessica Allen
BS University of Nevada, Las Vegas 2005, DMD UNLV 2011

Director: Thomas C. Waldrop, Professor, Director Graduate Periodontics, Department of Periodontics

Virginia Commonwealth University
Richmond, Virginia
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Abstract

MAXILLARY FURCATION EVALUATION: CLINICAL VERSUS CBCT MEASUREMENT

By Jessica Allen, DMD

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

Virginia Commonwealth University 2014

Major Director: Thomas C. Waldrop, Professor, Director Graduate Periodontics, Department of Periodontics

BACKGROUND: The use of three-dimensional imaging has shown to provide advantages to the clinician in assessing bone morphology. The aim of this study will be to compare the diagnostic efficacy of cone beam computed tomography (CBCT) versus diagnostic clinical measurements in patients presenting with furcation involved maxillary first molars.

METHODS: The study population included 20 patients with 34 maxillary first molar teeth with furcation involvement. Clinical horizontal and vertical probing measurements were compared to CBCT measurements taken by two calibrated examiners.

RESULTS: Horizontal measurements showed a significant difference between Glickman class II and class III. There were no statistical significant differences with the horizontal measurements between clinical probing, bone sounding and CBCT measurements. CBCT vertical measurements were statistically greater than clinical probing measurements.

CONCLUSION: The CBCT can provide similar horizontal measurements to standard clinical horizontal probing measurements and will provide a greater vertical dimension of a furcation defect to standard vertical probing measurements.

INTRODUCTION

Molar root anatomy, presence of cervical enamel projections, bifurcation ridges, enamel pearls and other contributing factors such as plaque-associated inflammation, trauma from occlusion, pulpal pathology, root fractures and iatrogenic factors can all be associated with furcation invasion.[1] Proper pre-surgical furcation diagnosis is generally performed with a good comprehensive periodontal examination by radiographic imaging and clinical probing, all of which are crucial to decision making in regards to periodontal treatment options.

Probing reliability plays a significant role in furcation diagnosis and treatment. Previous studies have described probing reliability being based on many factors such as the type of probe, probe tip diameter, presence of inflammation, probing force, angle, location of probing, and root anatomy.[2-6] Van der Velden et al. found a force of 0.75N puts the probe tip in the most coronal intact connective tissue fibers in shallow and deep pockets with a plateau force of 1.25N.[2] Fowler et al. found that in untreated patients the probe tip penetrated beyond the apical termination of the junctional epithelium into connective tissue and in treated patients the probe tip stopped coronal to apical termination of junctional epithelium.[3] Theil et al. found that probe readings are not a very precise measure of attachment loss, particularity with increasing severity of destruction and with multi-rooted teeth.[5]

Mealey et al. found clinical vertical and horizontal furcation measurements underestimated the furcation defect compared to surgical measurements.[7] Zappa et al. found a high amount of disagreement between clinical furcation diagnosis compared to actual surgical findings with 3-57% of clinical pretreatment diagnoses falling into the same degree category as the surgical diagnoses when using the Ramjford Index and 21-73% using the Hamp Index.[8] Moriarty et. al histologically evaluated periodontal probe penetration in untreated molar furcations. He found that while probing the interradicular site the probe did not follow the contours of the concave furcation, but penetrated the tissues at various levels along the furcation pocket wall and into the inflamed connective tissue.[9] Therefore, furcation measurements should be made adjacent to the furcation roots not in the interradicular space. However, Bower's et al. study indicated that deep root concavities in the mesial and distal furcation roots complicated probing against the roots in the furcation space.[10]

Glickman classification will be used in this study as an inclusion criterion. There are multiple classification systems described by authors such as Glickman et al. (1953), Goldman et al. (1958), Hamp et al. (1975), Ramfjord & Ash et al. (1979), Tarnow & Fletcher et al. (1984), Eskow & Kapin et al., Fedi et al. (1985) and Ricchetti et al. (1982).[1] Most classification systems only consist of a horizontal component with a few classifying the vertical component. Glickman was the first to classify furcations using the following criteria: - Grade I: Pocket formation into the flute of the furcation with intact interradicular bone, Grade II: Loss of interradicular bone and pocket formation of varying depths into the furcation but not completely probable to the opposite side of the tooth, Grade III: complete loss of interradicular bone with pocket formation that is completely probable to the opposite side of the tooth, Grade IV: Loss of attachment and gingival recession that has made the entire furcation clearly visible to clinical examination.[11] Hamp et al.

described the horizontal measurements as Degree I-III related to a 3mm horizontal increment. [12] Vertical measurements were classified by Eskow & Kapin et al.[8] along with Tarnow & Fletcher et al. [13, 14] As described earlier, the vertical dimension can be difficult to measure accurately but has been described as being able to provide more influence on the prognosis of a tooth than the horizontal component. [15]

Standard two-dimensional imaging provides additional information to the clinician in furcation management but has shown to have its limitations. Ross and Thompson et al. found that standard radiographs were able to detect known furcation invasion in 22% of maxillary and 8% of mandibular molars. [16] Hardekopf et al. found a relationship between a radiographic "furcation arrow" to the clinical presence of a furcation. The highest degree of association was with a mesial or distal Hamp degree III. However, the absence of a "furcation arrow" did not necessarily mean there was an absence of a furcation. [17] Standard dental radiographic imaging has its limitations in diagnosing furcation involvement, therefore, the use of three-dimensional imaging may provide the clinician with a better diagnostic tool for furcation diagnosis and management.

The body of literature does show an advantage to using CBCT imaging systems for diagnosing osseous defects with good dimensional accuracy. In an *in vitro* study Vandenberghe et al. found bone craters and furcation involvements were better depicted on CBCT compared to two-dimensional digital intraoral radiography. [18] In another study, Vandenberghe et al. found CBCT images of periodontal bone defects demonstrating values closer to measurements taken during surgical treatment. [19] Noujeim et. al created osseous defects of different depths and compared intraoral paralleling technique and limited volume CBCT and found that the CBCT provided better accuracy and diagnostic value than periapical films in the detection of interradicular periodontal osseous defects.[20] Multiple studies have shown the accuracy of CBCT *in vitro.* Moreira et al. found that a CBCT could obtain dimensionally accurate linear and angular measurements from bony maxillofacial structures and landmarks.[21] Lagravere et al. evaluated the accuracy of measurements on CBCT on a coordinate measuring machine and found linear measurements with variation up to 0.6mm and angular measurements varying less than a degree.[22] Thus CBCT could provide the clinician with a better standardized diagnostic tool to provide more reliable estimation of tooth prognosis and the proper treatment decisions.

When considering the use of CBCT to evaluate furcation defects, as with any radiographs taken for diagnostic purposes, the clinician should determine need for this radiographic selection. Recommendations have been made by the United States Federal Food and Drug Administration (FDA) to dental professionals in an initiative to reduce unnecessary radiation exposure from medical imaging. The FDA recommends that dental professionals discuss the rationale for the examination to the patient, provide justification for the radiological examination, review the patient's medical imaging history to avoid duplicate exams and use exposure settings for dental CBCT that are optimized to provide the lowest radiation dose that yields an image quality adequate for diagnosis (ALARA – as low as reasonably achievable).[23] Using the standard adult default settings, differentiating between small adult to large adult, of the Kodak 9500 CBCT unit Ludlow et. al found an effective dose for large field of view (FOV) ranging from 93-260 microsieverts and an effective dose for medium FOV ranging from 76-166 microsieverts using the 2007 International Commission on Radiological Protection (ICRP) calculations for determining effective dose. This information was then related to alternate measures of risk such as days of per capita background ranging from 11-32 days for large FOV and 9-20 days for medium FOV depending on the associated adult default setting. [24] In regards to the small FOV option, Ludlow et al. performed dosimetry calculations of the Kodak 9000 3D small FOV CBCT using the 2007 International Commission on Radiological Protection (ICRP) recommendations for calculating effective dose. The Kodak 9000 small field of view CBCT unit provides doses that are substantially lower (range 9.8-38.3 microsieverts) than the previously reported doses produced by medium and large FOV CBCT units. The difference in the range depends on the intraoral location that the small FOV is directed towards. Specifically the maxillary posterior region presented with an effective dose of 9.8 microsieverts which Ludlow et al. described as equivalent to 1 day of per capita background and presents with a 0.5 probability in 1 million fatal cancers. [25] These findings are comparable to effective doses in traditional dental radiography. [26] This small field of view will allow a localized view of the tooth in question with furcation involvement while providing the clinician and patient with an image that may allow proper treatment making decisions.

Upon diagnosing and control of the etiology, treatment of furcation defects can be performed either with open debridement, tunneling procedures, root resection, odontoplasty or regenerative techniques. Molar root anatomy, defect morphology and residual bone surrounding defect can provide the clinician with the proper regeneration prognosis and/or proper treatment protocol. In some cases proper furcation assessment may be only performed during an explorative open flap procedure. Dentists and patients seek the periodontist's opinion in reference to prognosis of teeth presenting with furcation involvement before finalizing their restorative or prosthodontic treatment plans. The limitations of 2 dimensional imaging and clinical measurements may implore the periodontist to perform exploratory surgery to determine the severity of the bone defect and the proper treatment modality. These on-the-spot treatment decisions may be very difficult and costly for patients. The advent of three-dimensional imaging has allowed dentistry to provide better treatment making decisions in questionable situations. In 2009 the Safety and Efficacy of a New and Emerging Dental X-Ray Modality(SEDENTEXCT)[27] project developed a set of evidence-based guidelines on CBCT for dental and maxillofacial radiology. Specifically to periodontics it states that the CBCT should not be routinely used for assessing periodontal bone support. The paper states that "the overall literature related to use of CBCT in periodontal imaging is small, mainly laboratory-based and involves a limited number of CBCT systems."[27, 28] The hope of this study is to provide the dental community with added information regarding the diagnostic capability of CBCTs in the presently small body of literature that has been published. This research will provide the clinician with insight into the accuracy of standard clinical probing measurements of furcation-involved teeth versus cone beam computed tomography (CBCT). The aim of this study is to compare the diagnostic efficacy of CBCT versus diagnostic clinical probing measurements in patients presenting with furcation involved maxillary first molars.

MATERIALS AND METHODS

I. Study population

The protocol for this study was reviewed by the Virginia Commonwealth University's Institutional Review Board (IRB). A study population from the VCU Graduate Periodontics patient pool was recruited and signed consent forms. The inclusion criteria consisted of patients with periodontal disease with one or more Glickman Class II or III furcation defects on maxillary first molars with horizontal and vertical components of at least 1mm. The treating periodontal resident classified the furcation defect after performing a comprehensive periodontal examination and reviewing radiographs. A calibrated examiner then confirmed the Glickman classification. The exclusion criteria consisted of uncontrolled systemic disease, history of radiation therapy, class I furcations (minimal bone loss), pregnant patients and patients under the age of 18.

II. Measurements

All patients who meet the inclusion and exclusion criteria were asked to participate in the study and given informed consent. Clinical measurements were taken and a small field of view (5x5) CBCT was taken with the Kodak 9000 3D CBCT unit (70kV, 10mA and 10.68 seconds) of the maxillary first molar exhibiting the furcation defect at the time of the initial periodontal examination, or anytime before mechanical debridement was performed at the site. If the patient was already treatment planned to have a CBCT taken due to other clinical needs, the field of view indicated for their treatment needs was used for the measurements of the study furcation.

1. Calibration of Examiners

Two VCU Periodontal residents took all measurements. Calibration was performed on a patient who presented with a furcation involved maxillary molar in a quadrant where a CBCT needed to be performed prior to implant placement. Both research examiners performed the clinical measurements as indicated in the study. Measurements were compared and if a difference of 2mm or greater occurred the examiners re-probed the area until both agreed on the proper technique to reproduce measurements as indicated by the research protocol. CBCT measurements of the previously clinically examined maxillary molars was performed and if the measurements were off by 2mm or greater both examiners evaluated the measuring technique so proper technique and measurements would be taken the same way for all research subjects.

2. Clinical Measurements

Clinical measurements consisted of horizontal and vertical furcation measurements. The horizontal furcation measurements were taken with a Nabers Probe (Hu-Friedy) starting at the furcation entrance to the greatest horizontal depth. Measurements were recorded by two calibrated examiners and rounded up to the nearest millimeter. The vertical measurements were taken with a straight periodontal probe (Hu-Friedy UNC probe) starting at the furcation entrance and running the probe along the root surface until deepest vertical component was measured. Measurements were recorded by two calibrated examiners and rounded up to the nearest millimeter. If patient agreed to further participate in the study and were treatment planned for scaling and root planning, bone sounding measurements were taken under local anesthesia in the horizontal and vertical direction by two calibrated examiners at the time of their scaling and root planning appointments. The two examiners were blinded to each other's values.

3. Cone Beam Computed Tomography (CBCT) measurements

CBCT measurements were performed by measuring the deepest vertical and horizontal furcation defects at each furcation entrance. The furcation entrance was used as the anatomical starting point using the measuring tool provided within the Kodak software (Oblique view, Carestream 3D Imaging Software Version 3.1). Two calibrated examiners completed the measurements. The examiners did not have access to clinical measurements while evaluating the CBCTs. The CBCT measurements were analyzed in the axial, sagittal and coronal sections that made the defect most visible and easily measured. The furcation entrance was used as the anatomical location to align the cross-sections of the different planes. Scrolling back and forth in the different planes allowed the examiners to identify and measure the most vertical and horizontal extent of bone loss. These measurements were then recorded and compared to clinical findings. The two examiners were blinded to each other's values.

III. Statistical methods

Statistical analysis was performed to evaluate repeatability among examiners for probing, CBCT and bone sounding measurements using Pearson correlations as well as Spearman's correlation. The mean measurements taken with each measuring modality were evaluated and significant relationships were determined among the horizontal and vertical measurements with type of furcation, furcation site and the type of measurement technique used.

Two separate Analysis of Variance models were used to determine the effect of a number of factors on the vertical and horizontal measurements. The models used the patient as a random effect and the fixed effects were location of the furcation (M, D, B), type of measurement (BS, CBCT, PD), and type of the furcation (2, 3). Tukey's multiple comparison's test ($p < 0.05$) was used when there were more than two levels of the factor. An alpha of 0.05 was considered significant.

RESULTS

I. Description of the sample population

Table 1 summarizes the demographics of the study population. A total of 25 VCU School of Dentistry Graduate Periodontics Department patients agreed to participate in the study with 20 completing clinical and CBCT measurements (9 male and 11 female). The average age of the population was 60 years old with a range of 39-77 years old. Five out of the 20 people were current smokers. Five out of the 20 people had a positive medical history for diabetes. The total number of furcations examined were 34, of which, 32 were classified as Glickman Class II and 2 as Glickman Class III. Fourteen of the furcations were located on the buccal, 14 on the distal/palatal and 6 measured on the mesial-palatal.

II. Furcations Examined

The following data is summarized in table 2. The horizontal measurements of the Glickman Class III furcations were on average greater than the vertical measurements. The mean horizontal measurement for the Glickman Class III furcations for probing and CBCT were 5.50mm (N = 2, ±0.00mm) and 6.15mm (N = 2, ±0.92mm), respectively. The mean vertical measurement for the Glickman Class III furcations for probing and CBCT were 4.25mm (N = 2, ±0.35mm) and 4.95mm (N = 2, ±0.28mm), respectively. The mean horizontal and vertical measurements for the

Glickman class II furcations were similar. The mean horizontal measurement for the Glickman Class II furcations for probing, bone sounding and CBCT were 3.03mm (N = 32, ±1.05mm), 3.45mm (N = 10, ±1.17mm) and 3.00mm (N = 31, ±1.28mm), respectively. The mean vertical measurement for the Glickman Class II furcations for probing, bone sounding and CBCT were 2.95mm (N = 32, ±1.19mm), 4.05mm (N = 10,±1.57mm) and 3.59mm (N = 31, ±2.18mm), respectively. The Glickman class II furcations for both horizontal and vertical measurements found bone sounding to have the greatest measurement compared to CBCT and clinical probing. The horizontal measurement on average was very similar between the CBCT and clinical probing measurements. The vertical measurement showed clinical probing to have the smallest measurement.

The mean horizontal measurement for buccal furcation sites for probing, bone sounding and CBCT were 3.25mm (N = 14, ±1.41mm), 4.00mm (N = 3, ±1.73mm) and 3.87mm (N=13,±1.63mm), respectively (Table 3). Bone sounding presenting with the greatest measurement followed by CBCT measurements and then clinical probing measurements. The mean vertical measurement for buccal furcation sites for probing, bone sounding and CBCT were 3.00mm (N = 14, ±1.44mm), 4.67mm (N = 3, ±2.47mm) and 3.30mm (N = 13, ±2.29mm), respectively (Table 3). Bone sounding presented with the greatest vertical measurement, followed by CBCT and then clinical probing. The horizontal and vertical buccal furcation measurements were on average greater for the bone sounding followed by CBCT and then clinical probing.

The mean horizontal measurement for distal furcation sites for probing, bone sounding and CBCT were 3.04mm (N = 14, ±0.93mm), 2.88mm (N = 4, ±1.03mm) and 2.52mm (N = 14,

±0.85mm), respectively (Table 3). The horizontal measurement for the distal furcation sites presented with clinical probing having the greatest measurement, followed by bone sounding and then CBCT measurement being the least. The mean vertical measurement for distal furcation sites for probing, bone sounding and CBCT were 2.71mm (N = 14, ±0.85mm), 3.25mm (N = 4, ±0.87mm) and 3.39mm (N = 14, ±1.77mm), respectively (Table 3). The distal furcation vertical measurement found CBCT to be the greatest measurement followed by bone sounding and then clinical probing.

The mean horizontal measurement for mesial furcation sites for probing, bone sounding and CBCT were 3.33mm (N = 6, ±1.25mm), 3.67mm (N = 3, ±0.58mm) and 3.30mm (N = 6, ±1.75mm), respectively (Table 3). The horizontal measurement showed bone sounding to have the greatest measurement followed by probing and CBCT which were not significantly different. The mean vertical measurement for distal furcation sites for probing, bone sounding and CBCT were 3.83mm (N = 6, ±1.03mm), 4.50mm (N = 3, ± 1.32mm) and 5.10mm (N = 6, ±2.34mm), respectively (Table 3). The vertical measurement on average showed CBCT to have the greatest vertical measurement followed by bone sounding and then clinical probing.

Overall, the buccal furcation horizontal and vertical measurements were greatest for bone sounding followed by CBCT and then clinical probing. The distal and mesial furcation sites were not as straightforward with variations between the 3 measurement modalities. The mesial and distal horizontal furcation measurements overall showed bone sounding and probing to both have greater measurements than the CBCT measurements but this was not statistically significant. The vertical measurements for mesial and distal furcation sites overall showed the CBCT to provide the greatest measurement followed by bone sounding and then clinical probing.

III. Repeatability among examiners

In regards to bone sounding, both examiners agreed 80% of the time with the horizontal measurement and agreed 40% of the time with the vertical measurement (Table 4). Disagreement among examiners for the horizontal measurement occurred 20% of the time, with a 1mm difference 10% of the time and a 2mm difference 10% of the time (Table 4). Disagreement among examiners for the vertical measurement occurred 60% of the time. Fifty percent of the time this disagreement was no greater than 1mm and 10% of the time it was no greater than 2mm (Table 4). Bone sounding tended to have better agreeability in the horizontal direction than the vertical direction among examiners. If you allow for a 1mm measurement error the agreement among examiners was 90% for both horizontal and vertical measurements. To further evaluate the agreeability among examiners for bone sounding, Pairwise and Spearman correlations were performed. Pairwise correlations among examiners for horizontal and vertical measurements were 0.85 and 0.83, with a Spearman correlation of 0.75 and 0.57, respectively (Table 9a and 9b). This was not found to be significant as there was not an adequate sample size to provide significant correlation with bone sounding measurements.

Regarding clinical probing measurements, the examiners agreed 53% of the time for the horizontal measurement and agreed 59% of the time for the vertical measurement (Table 5). The horizontal measurements were in disagreement 47% of the time, with a 1mm difference 41% of the time and 2mm difference 6 % of the time (Table 5). The vertical probing measurements were in disagreement 41% of the time, with a 1 mm difference 35% of the time and 2mm difference 6% of the time (Table 5). If you allow for a 1mm measurement error both examiners agreed 94% of the time for both horizontal and vertical measurements. Pairwise correlations among examiners for horizontal and vertical measurements were 0.79 and 0.83, with a Spearman correlation of 0.73 and 0.84, respectively. Both being clinically significant with a p value of <0.0001 (Table 8a and 8b).

Both examiners had high agreeability/repeatability for the CBCT horizontal and vertical measurements. The mean difference in disagreement among examiners being 0.01mm ±0.37mm for the horizontal measurement and 0.18mm ±0.32mm for the vertical measurement (Table 6). Pairwise correlations among examiners for horizontal and vertical CBCT measurements were 0.97 and 0.99 along with a Spearman correlation of 0.95 and 0.98, respectively (Table 7a and 7b). This being clinically significant with a p value of <0.0001.

The sample size was 10 for bone sounding whereas the sample size for CBCT measurements was 33 and probing measurements was 34. The small sample size for bone sounding was associated with limited number of patients wanting to either proceed with the study or patients that did not follow through with additional treatment needs. CBCT measurements were the most highly correlated type of measurement among examiners.

IV. Hypothesis Testing

When averaging the horizontal measurements the only significant difference was found among type of furcation, if the furcation was a class III it always had a higher mean measurement versus the class II furcations (5.71mm±0.74mm vs. 3.20mm±0.20mm, respectively) with p value of 0.0016 (Table 10). On average, horizontal measurements between different furcation sites (Buccal 4.73mm±0.42mm vs Distal 4.25mm±0.47mm vs Mesial 4.38mm±0.45mm) was similar with no significant difference (Table 10). The mean difference of the horizontal aspect using the different types of measurements (Probing vs BS vs CBCT) was similar with no significant difference (Table 10).

In regards to the vertical measurement, there was no significant difference between the different types of furcations (class II 3.68mm±0.37mm VS Class III 4.62mm±0.94mm) (Table 11). There was a significant difference among furcation sites with the mean vertical measurement being significantly greater on the mesial furcation (4.86mm±0.61mm) versus the buccal furcation (3.43mm±0.56mm) with a p value of 0.0124 (Table 11). No significant difference was found regarding the mean measurement of the distal furcation (4.12mm±0.65mm) vertical measurement among the buccal and mesial furcation (Table 11). There was a significant difference between the type of measurement technique utilized to measure the vertical aspect of the furcation defect. On average, the CBCT measurements were significantly greater than probing measurements (4.27mm±0.56mm vs 3.66mm±0.56mm, respectively) with a p value of 0.0223 (Table 11). There was no significant difference in regards of the bone sounding measurement in the vertical aspect of the defect (4.53mm±0.64mm) versus probing or CBCT measurements (Table 11).

DISCUSSION

The purpose of this study was to evaluate whether standard clinical measurements of furcation defects at the initial examination appointment differ from CBCT measurements. The horizontal measurements were similar among the different measuring modalities. There was a significant difference between clinical probing and CBCT measurements when evaluating the vertical aspect of the furcation defect, with the CBCT measurements being significantly greater than the probing measurements. According to these results, the greatest variability the clinician may encounter is the vertical measurement of the furcated tooth. This vertical defect may be more severe then indicated during the initial clinical exam. Along with these findings, the study also found that among examiners, CBCT measurements of furcation defects had higher agreement than clinical probing measurements. Therefore, the CBCT may provide the patient with a more uniform diagnosis from clinicians regarding extent of furcation involvement.

It is necessary to keep in mind that horizontal measurements taken with the CBCT are linear and when you compare these linear measurements to clinical measurements taken with a curved Naber's probe one may expect some variability. Eickholtz et al. evaluated interexaminer reproducibility of horizontal attachment levels in furcations using a Nabers probe and a straight True Pressure Sensitive (TPS) periodontal probe. The type of probe did not influence interexaminer reproducibility and did not influence probing attachment levels into the furcation at a statistically significant level.[29] Our study showed no statistically significant difference between the CBCT and clinical horizontal probing measurements, indicating that a curved Nabers probe provides a measurement similar to a linear measurement taken on CBCT.

Correlating CBCT measurements to intrasurgical findings has been found to have a high degree of agreement. Eighty-four percent of CBCT diagnosed furcation involvement correlated with intrasurgical measurements.[30] Based on these findings, you would assume the CBCT measurements would be greater than clinical probing measurements and more correlated with bone sounding measurements. Unfortunately, this study did not have enough bone sounding measurement sites to grasp any significant relationships between bone sounding, clinical probing and CBCT measurements. In this study, there was a trend of CBCT measurements being greater than clinical probing measurements in most sites (Table 3). This correlates with previous studies that have shown CBCT measurements to have a high degree of agreement to intrasurgical measurements. The fact that the distal and mesial horizontal furcation measurements did not follow this trend may be explained by clinical probing measurement error. Eickholtz et al. found that furcation location influenced the horizontal probing attachment level with the distolingual furcation site having the highest variability among examiners.[29]

Mealey et al. found clinical probing measurements of furcation-involved molars to be mainly underestimated in both the horizontal (0.63mm) and vertical (1.85mm) aspect compared to intrasurgical measurements.[7] This underestimation in clinical measurements of the vertical aspect correlates with the findings of this study. Walter et al. found that the degree of furcation involvement for maxillary molars noted during clinical examination only correlated with CBCT measurements 27% of the time, while 29% of clinical measurements were overestimated and

44% were underestimated. [31] A more recent article found the degree of furcation involvement was confirmed with the CBCT only 57% of the time. Compared to the CBCT, the clinical determination of furcation involvement was overestimated 20% and underestimated 23% of the time. [32] The latter 2 articles used the Hamp furcation classification system, which uses a 3mm increment to differentiate the degree of furcation involvement. This study used a diagnosis of Glickman Class II or III to ensure a certain amount of bone loss. The examiners purposely avoided a classification system that separates furcation severity by an arbitrary millimeter increment. This was done to avoid reclassification as a result of a measurement error. This allowed me to use standard probing instruments to directly compare to measurements that could be captured on the CBCT. As noted in the results, the standard probing instruments used by both examiners were fairly accurate in capturing a similar horizontal measurement of the furcation defect. However, the vertical measurement on the CBCT was significantly greater than clinical probing measurements. All the furcation defects were true to their initial Glickman Classifications. The only variability noted was with the degree of root morphology, which may not have allowed enough room to adequately probe the defect. In one case there was extensive buccal exostosis giving a false positive to a clinically probable furcation involvement.

There are added benefits to the diagnostic capabilities of CBCTs that may not be available with initial clinical probing and two-dimensional imaging. These benefits include dimensional accuracy of the defect, the number of walls present on the defect, communication with the maxillary sinus, periapical pathology that did not present itself on the standard intraoral radiographs and providing a better teaching tool for apprehensive patients who may agree to the increased risk of radiation exposure to avoid uncertain financial costs. [18, 32-35] Data from the

CBCT facilitated a reduction in treatment costs for periodontally involved maxillary molars in cases where maximal invasive treatments were recommended. [35]

Just as there are inherent errors in clinical measurements, this study presented with aspects that should be addressed and evaluated by the clinician to avoid problems with the diagnostic capabilities of the CBCT. The presence of silver points or gutta percha in root canals, adjacent large amalgam restorations, full coverage crowns and implants provided scatter in the CBCT that made measuring some of the osseous defects somewhat more difficult. Bone density in the posterior maxilla, patient movement at the time of capturing the image, CBCT machine malfunctions and operator error are additional aspects that can cause difficulty in properly assessing the osseous defect. All these things need to be considered by the clinician when determining if a CBCT image should be used for diagnostic purposes.

As described in the introduction, radiation dose associated with CBCT needs to be considered when deciding upon this as a diagnostic modality. The ability of x-rays to induce mutations in DNA can increase the risk of cancer with children being most susceptible. [24, 36] Ludlow et al. describes an increase in the number of CBCT units being purchased by non-radiology practices and individuals with little training in radiation biology and protection. Manufacturers play critical roles in examination doses based on their default exposure settings and options. [24] Different manufactures demonstrate different amounts of ionizing radiation with their CBCT units. [36] Efforts from manufactures to reduce effective doses of ionizing radiation in new and post-release CBCT units are imperative to provide patient populations with the lowest dose of ionizing radiation in compliance with the ALARA recommendation.

The ICRP recommendations for tissue/organ weighting factors are regularly updated by the ICRP and clinicians need to be aware that most articles comparing CBCT units effective dose measurements published before the new 2007 ICRP recommendations will have an underestimation of effective doses for the same level of irradiation. The effective dose calculation has been increased from the 1990 ICRP recommendations due to updates that were made to include salivary glands and changes in some tissue-weighting factors according to recent rates of cancer incidence.[36] The smaller FOV normally generates lower levels of radiation but in general the mandibular small FOV will present with larger radiation dose due to its proximity to salivary glands, thyroid and esophagus. [36] The dosage for digital/F-speed complete full mouth series with rectangular collimation is 34.9 microsieverts, bitewings using digital/F-speed with rectangular collimation is 5 microsieverts and panoramic films being 24.3 microsieverts. [26] Dental radiation doses are very low compared to other medical imaging techniques and even to cosmic radiation emitted to commercial aviation crewmembers. To provide perspective, Bagshaw et al. found that long-haul pilots averaged an annual mean effective exposure of 2-3mSv and epidemiological studies of flight crew have not shown conclusive evidence for an increase in cancer mortality and incidence.[37] A round trip from Paris to Tokyo was found to have a cosmic radiation dose of about 129±10[38] microsieverts.[38] The ICRP maximum mean effective dose limits for the general public is 1 millisiverts (mSv) yr^{-1}, occupationally exposed is 20mSv yr^{-1} for a 5 year average with no more than 50mSv in a single year and for pregnant individuals no more than 1mSv for the duration of the pregnancy. [39] This study utilized Kodak 9000 small field of view CBCT unit that provided a dose of 9.8 microsieverts in the posterior maxilla. These dosage levels are well below the ICRP maximum mean effective dose limits, and comparable to current dental radiographic radiation doses.

The application of CBCT in the dental field as a diagnostic tool to evaluate osseous defects may provide additional benefits to the clinician to address furcation involvements. In this study, clinical measurements obtained during an initial periodontal examination provided similar findings of the osseous defect in the horizontal aspect but the vertical aspect was significantly underestimated compared to CBCT measurements. The utility of small field of view CBCT imaging can provide the clinician and the patient with benefits to evaluating and treating osseous defects. This study certainly does not rule out the need for a comprehensive periodontal examination by a dental professional, but it may allow justification to the clinician, especially the Periodontist, to use CBCT imaging to accurately assess osseous defects at furcation sites.

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Appendix A

Table 1: Demographics

	Number of subjects	Number of Furcations examined	Mean Age (Range)	Current Smokers		Diabetics	
Male	9			No	Yes	No	Yes
Female	11						
Total	**20**	**34**	**60 (39-77)**	**15**	**5**	**15**	**5**

Appendix B

Table 2: Furcation Classification – The mean measurement found for the associated furcation classification.

Furcation Classification			Horizontal		Vertical	
Types of furcations	**Type of Measure**	**N**	**Mean (mm)**	**Std Dev**	**Mean (mm)**	**Std Dev**
2	BS	10	3.45	1.17	4.05	1.57
	CBCT	31	3.00	1.28	3.59	2.18
	Probing	32	3.03	1.05	2.95	1.19
3	CBCT	2	6.15	0.92	4.95	0.28
	Probing	2	5.50	0.00	4.25	0.35

Table 3: Furcation Location – Mean measurement for the furcation location.

Furcation Location			**Horizontal**		**Vertical**	
Site	**Type of measure**	**N**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
B	BS	3	**4.00**	1.73	**4.67**	2.47
	CBCT	13	**3.87**	1.63	**3.30**	2.29
	P	14	**3.25**	1.41	**3.00**	1.44
D	BS	4	**2.88**	1.03	**3.25**	0.87
	CBCT	14	**2.52**	0.85	**3.39**	1.77
	P	14	**3.04**	0.93	**2.71**	0.85
M	BS	3	**3.67**	0.58	**4.50**	1.32
	CBCT	6	**3.30**	1.75	**5.10**	2.34
	P	6	**3.33**	1.25	**3.83**	1.03

Appendix C

Table 4: Bone Sounding – Percent agreement between examiners for bone sounding measurements.

Type of Measurement- Bone sounding (BS)					
Horizontal			Vertical		
Difference in measurement (mm) between J and A	Frequency of Horizontal Difference	Probability	Difference in measurement (mm) between J and A	Frequency of Vertical Difference	Probability
-2	1	0.10000	-1	3	0.30000
-1	1	0.10000	0	4	0.40000
0	8	0.80000	1	2	0.20000
			2	1	0.10000
Total	**10**	**1**	**Total**	**10**	**1**

Table 5: Probing - Percent agreement between examiners for clinical probing measurements.

Type of Measurement- Probing (P)					
Horizontal			Vertical		
Difference in measurment (mm) between J and A	Frequency of Horizontal Difference	Probability	Difference in measurment (mm) between J and A	Frequency of Vertical Difference	Probability
-2	2	0.05882	-1	6	0.17647
-1	7	0.20588	0	20	0.58824
0	18	0.52941	1	6	0.17647
1	7	0.20588	2	2	0.05882
Total	**34**	**1**	**Total**	**34**	**1**

Appendix D

Table 6: Cone Beam Computed Tomography (CBCT) – Percent agreement between examiners for CBCT measurements.

Type of Measurement - CBCT			
Horizontal		Vertical	
Difference in measurment (mm) between J and A		Difference in measurment (mm) between J and A	
Mean	**-0.01**	**Mean**	**-0.18**
Std Dev	0.37	Std Dev	0.32
Std Err Mean	0.06	Std Err Mean	0.06
Upper 95% Mean CI	0.12	Upper 95% Mean CI	-0.07
Lower 95% Mean CI	-0.14	Lower 95% Mean CI	-0.29
N	33	N	33

Appendix E

Table 7(a), (b): Cone Beam Computed Tomography (CBCT)
7(a) Pearson Correlation, (statistically significant * at p<0.0001) – Correlation between examiners for CBCT measurements.

Type of Measurement - CBCT					
Horizontal measurement (mm)		Count	Lower 95%	Upper 95%	Signif Prob
Examiner J vs Examiner A	**0.97**	33	0.94	0.99	<.0001*
Vertical measurement (mm)		Count	Lower 95%	Upper 95%	Signif Prob
Examiner J vs Examiner A	**0.99**	33	0.98	0.99	<.0001*

7(b) Spearman Correlation, (statistically significant * at p<0.0001)

Type of Measurement - CBCT					
Horizontal measurement (mm)	Spearman ρ	Prob>|ρ|	Vertical measurement (mm)	Spearman ρ	Prob>|ρ|
Examiner J vs Examiner A	**0.95**	**<.0001***	Examiner J vs Examiner A	**0.98**	**<.0001***

Appendix F

Table 8(a), (b): Probing
8(a) Pearson Correlation, (statistically significant * at p<0.0001) - Correlation between examiners for clinical probing measurements.

Type of Measurement - Probing					
Horizontal measurement (mm)		Count	Lower 95%	Upper 95%	Signif Prob
Examiner J vs Examiner A	**0.79**	34	0.62	0.89	<.0001*
Vertical measurement (mm)		Count	Lower 95%	Upper 95%	Signif Prob
Examiner J vs Examiner A	**0.83**	34	0.68	0.91	<.0001*

8(b) Spearman Correlation, (statistically significant * at p<0.0001)

Type of Measurement -Probing					
Horizontal measurement (mm)	Spearman ρ	Prob>|ρ|	Vertical measurement (mm)	Spearman ρ	Prob>|ρ|
Examiner J vs Examiner A	**0.73**	**<.0001***	Examiner J vs Examiner A	**0.84**	**<.0001***

Appendix G

Table 9(a), (b): Bone Sounding
9(a) Pearson Correlation - Correlation between examiners for bone sounding measurements.

Type of Measurement -BS					
Horizontal measurement (mm)		Count	Lower 95%	Upper 95%	Signif Prob
Examiner J vs Examiner A	**0.85**	10	0.47	0.96	0.0020*
Vertical measurement (mm)		Count	Lower 95%	Upper 95%	Signif Prob
Examiner J vs Examiner A	**0.83**	10	0.41	0.96	0.0032*

9(b) Spearman Correlation

Type of Measurement -BS					
Horizontal measurement (mm)	Spearman ρ	Prob>|ρ|	Vertical measurement (mm)	Spearman ρ	Prob>|ρ|
Examiner J vs Examiner A	**0.75**	**0.0124***	Examiner J vs Examiner A	**0.57**	**0.0843**

Appendix H

Table 10: Hypothesis Testing, Horizontal Measurements – Average measurement difference between Glickman class 2 and 3 when combining all measurement modalities (Probing, BS and CBCT), average furcation measurement per site (mesial vs distal vs buccal) when combining all measurement modalities (Probing, BS and CBCT) and average measurement difference when comparing the measurement modalities (Probing, BS and CBCT).

Horizontal Measurements						
Type of Furcation	Class 2	Std Error	Class 3	Std Error		
Mean measurement (mm)	**3.20***	0.20	**5.70***	0.74		
*** Only significant difference (0.0016)**						
Furcation Site	Buccal	Std Error	Distal	Std Error	Mesial	Std Error
Mean measurement (mm)	4.73	0.42	4.25	0.47	4.38	0.45
Type of measurement (P-Probing, BS - Bone Sounding, CBCT)	BS	Std Error	CBCT	Std Error	P	Std Error
Mean measurement (mm)	4.82	0.50	4.23	0.40	4.26	0.40

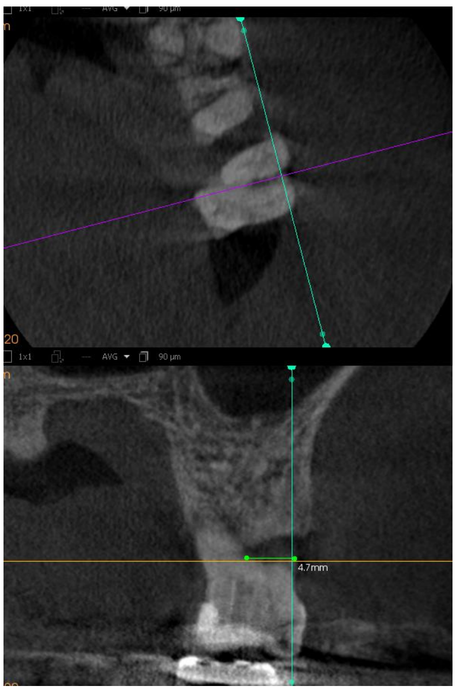
Appendix I

Table 11: Hypothesis Testing, Vertical Measurements - Average measurement difference between Glickman class 2 and 3 when combining all measurement modalities (Probing, BS and CBCT), average furcation measurement per site (mesial vs distal vs buccal) when combining all measurement modalities (Probing, BS and CBCT) and average measurement difference when comparing the measurement modalities (Probing, BS and CBCT).

Vertical Measurements						
Type of Furcation	Class 2	Std Error	Class 3	Std Error		
Mean measurement (mm)	3.68	0.37	4.62	0.94		
Furcation Site	Buccal	Std Error	Distal	Std Error	Mesial	Std Error
Mean measurement (mm)	**3.43***	0.56	4.17	0.65	**4.86***	0.61
*** Significantly different among Buccal and Mesial (0.0124)**						
Type of measurement (P-Probing, BS - Bone Sounding, CBCT)	BS	Std Error	CBCT	Std Error	P	Std Error
Mean measurement (mm)	4.53	0.63	**4.27***	0.56	**3.66***	0.56
*** Significantly different among CBCT and Probing (0.0223)**						

Appendix J

Figure 1: CBCT Horizontal and Vertical measurement Glickman Class II



Appendix K

Figure 2: CBCT Horizontal and Vertical measurement Glickman Class III