COMPARISON OF MESIODISTAL ROOT ANGULATION USING POST-TREATMENT PANORAMIC RADIOGRAPHS AND CONE BEAM COMPUTED TOMOGRAPHY

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ABSTRACT

DANIEL G. BOUWENS: Comparison of Mesiodistal Root Angulation Using Post-Treatment Panoramic Radiographs and Cone Beam Computed Tomography (Under the direction of Dr. Ceib Phillips)

The purpose of this project is to compare mesiodistal root angulations using post-treatment panoramic radiographic images and CBCT scans. Mesiodistal root angulations using panoramic images and cone beam computed tomography scans obtained on 35 orthognathic surgery patients at the completion of orthodontic treatment were compared. Panoramic images were measured using VixWin and NewTom CBCT scans using InvivoDental 3D. The mesiodistal root angulations of each upper and lower tooth were measured using the occlusal plane as the reference line. Using an intercept-only linear regression for correlated data (with an unstructured covariance structure), the global test of whether the mean vector of all the differences for the teeth is zero was performed separately for the maxillary and mandibular arch. The global test for both the maxillary and mandibular arch was statistically significant (P<0.001) indicating an overall difference in root angulation between measures from panoramic and CBCT images.
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Orthodontists rely on patient records to enhance diagnosis, treatment planning, patient and colleague communication, and progress and outcome evaluation. Patient records typically include a clinical examination, intraoral and extraoral photographs, panoramic and cephalometric radiographs, and study models. A recent survey of American private practitioners regarding orthodontic diagnosis and treatment protocols revealed 67.4% and 80.1% of survey participants reported utilizing progress and post-treatment panoramic radiographs, respectively.\(^1\)

A major limitation of current diagnostic records, aside from study models, is that these standard records rely on two-dimensional representations of three-dimensional patient anatomy. Recently, the incorporation of three-dimensional imaging in the orthodontic patient record has increased because each two-dimensional record is developed with inherent inadequacy due to image overlap and distortion.

*Axial Inclination*

A primary objective of orthodontic treatment is the establishment of proper tooth positions in three planes of space, so that tooth positions approach predefined cephalometric and occlusal standards.\(^2\) In his historic study of dental occlusion, Andrews\(^3\) concluded proper mesiodistal axial inclination (tip) of the dentition is one of the six keys to the development of ideal occlusion. Assessing root parallelism during orthodontic treatment has
frequently been mentioned in the orthodontic literature to help align teeth within the apical base and orient occlusal forces parallel to the long axis of the teeth. Additional investigators have associated root parallelism with post-treatment stability, especially in pre-molar extraction cases.\textsuperscript{4,5} Jarabak and Fizzel\textsuperscript{6} indicated lack of root parallelism at extraction sites would result in occlusal forces exerting a rotational force on teeth and additionally there would be greater risk of periodontal injuries in patients with poor oral hygiene. Graber\textsuperscript{7} stated extraction sites would exhibit greater potential to re-open without root parallelism and Edwards\textsuperscript{8} indicated root parallelism would be accomplished by the conscientious clinician prior to appliance removal. As a portion of the American Board of Orthodontics (ABO) clinical case evaluation, the panoramic radiograph is required for the assessment of tooth inclination and root parallelism to evaluate the adequacy of orthodontic finishing. The ABO maintains the method is reasonable although not ideal and recently discontinued the evaluation of maxillary and mandibular canine inclinations using panoramic radiographs.\textsuperscript{9}

\textit{Panoramic Radiographic Imaging}

Panoramic radiography, initially developed by Paatero\textsuperscript{10} in 1948, is an excellent imaging technique if used with the recognition that it has greater value for screening than diagnostic purposes. The panoramic radiograph is advantageous in evaluation of orthodontic patients due to the broad anatomic region imaged, relatively low patient radiation dose, and the convenience, ease, and speed of the procedure. Panoramic imaging is commonly used to provide information about mandibular symmetry, present and missing or supernumerary teeth, dental age and eruption sequence. More limited information concerning gross periodontal health, sinus disease, temporomandibular joint (TMJ) condition, and bony pathology or variations from normal may also be evaluated from the panoramic image.\textsuperscript{11}
Panoramic radiography, in addition to clinical evaluation, is frequently utilized throughout the course of orthodontic treatment to assess root angulation to guide bracket repositioning or finishing archwire bends.

Panoramic imaging discrepancies arise due to the creation of a focal trough designed to conform to a nonspecific jaw size and form. The focal trough is a mathematical concept used to calculate the position of the dental arches in order to achieve the clearest image. Divergence from the nonspecific jaw form within individual patients results in alterations in size, location, and form compared with the actual subject because structures cannot be centered within the focal trough.\textsuperscript{12,13} Further disadvantages of panoramic radiography include lack of fine detail and variable magnification and geometric distortion due to the method of image acquisition. Radiographic images are best suited for interpretation and measurements when the object and film are parallel to one another and perpendicular to the beam. However, panoramic image acquisition entails sizeable deviations of beam directions from perpendicular, particularly in the premolar region.\textsuperscript{14}

The aforementioned limitations of panoramic imaging have led clinicians to perform diagnosis and treatment planning based on a collection of geometrically unrelated and inaccurate two-dimensional images. Comparisons assessing panoramic representations and mesiodistal root angulations in three-dimensions are needed to critically appraise panoramic images. It seems clear that the significantly greater amount of information acquired with 3D imaging techniques has the potential to allow for more thorough diagnosis, treatment planning, and assessment of change over time.
Previous studies of panoramic radiographic image distortion

Numerous investigators have examined focal trough, projection angle, horizontal and vertical magnification, angular distortion, and patient positioning and their effects on the dimensional accuracy of panoramic images.\textsuperscript{5,14-18} Variable degrees of distortion arise in different regions of the craniofacial complex within panoramic images.\textsuperscript{19-22} Angular distortion within the radiograph results from the combined effects of distortion in the horizontal and vertical planes and varying locations and depths within the focal trough.\textsuperscript{23}

When the x-ray beam is not perpendicular to the dental arch while imaging adjacent teeth possessing different buccolingual angulations (torque) it is likely that the resultant image will produce a false assessment of root misalignment in a mesiodistal plane (tip). Thus, any alteration of buccolingual inclination is registered as a deviation in mesiodistal angulation on the panoramic image and evaluation of root angulation via panoramic radiography following orthodontic closure of extraction spaces may be imprecise.\textsuperscript{4,24}

Phillip and Hurst\textsuperscript{25} studied the effect of cant of the occlusal plane relative to the plane of image acquisition using a series of soldered wires representing teeth with “parallel” roots. They found the greatest degree of distortion of parallelism in the canine and premolar regions of both arches. McDavid\textsuperscript{18} et al demonstrated angular distortion of the image results from variation in both vertical and horizontal magnification due to common patient positioning errors. Xie\textsuperscript{16} et al recommended vertical measurements be taken from panoramic radiographs via a horizontal reference line located anatomically immediately above or below the point being measured and in a plane in the center of the focal trough.

Lucchesi\textsuperscript{4} et al utilized steel pins representative of tooth roots within a Plexiglas mandibular phantom to study the appropriateness of assessing tooth inclinations within the
mandible via panoramic imaging. The steel pins were manipulated to allow alterations in mesiodistal and buccolingual inclination. They found greater deviations from actual mesiodistal inclinations were present in the anterior region, as well as accentuated deviations in both the positive and negative direction with increased lingual inclination of the steel pins. Lucchesi et al concluded an explanation for these findings was difficult to construe as it would be anticipated that errors would occur in either a positive or negative direction.

McKee et al used a test skull and typodont to compare mesiodistal root angulations from four different panoramic units to true anatomic angulations. A tridimensional coordinate measuring system was used to calculate true mesiodistal tooth inclinations relative to the arch wire. Following imaging of the test skull in each of the four panoramic units they found statistically significant differences for 74% of maxillary and mandibular tooth inclinations in relation to true mesiodistal inclinations, which were fairly evenly distributed among each of the four imaging units. Within the maxilla, the posterior tooth roots were projected more distally and anterior tooth roots more mesially generating a false impression of divergence between canine and first premolar. Within the mandible, all tooth inclinations were projected more mesially except the right central incisor with the greatest deviations occurring in the region of the canine and first premolar. They found that even after imposing a clinically significant tolerance limit of 2.5° that 61% of maxillary and mandibular tooth inclinations exhibit clinically significant deviations from true tooth inclination on the panoramic image and concluded the radiographic assessment of mesiodistal root angulation via panoramic imaging should be approached with extreme caution.

In a related but independent investigation McKee et al studied the consequence of common patient positioning errors during panoramic image acquisition on the resulting
Imaged mesiodistal tooth inclinations using a test skull and typodont. The skull was imaged in ideal head position and with 5° of deviation up, down, left and right. The results demonstrated maxillary teeth were more sensitive to up/down head rotation and mandibular anterior teeth were more sensitive to right/left head rotation with 64% of image angles from the deviated head positions statistically significantly different than image angles from the idealized head position. The authors recognized the differing sensitivities between maxillary and mandibular teeth with regards to up/down and left/right rotations were difficult to explain and concluded the clinical assessment of mesiodistal tooth angulation with panoramic radiography should be approached with extreme caution with an understanding of the inherent image distortions that can be further complicated by the potential for aberrant head positioning.

In a similar study, Hardy et al investigated the changes in mesiodistal axial inclination of teeth on panoramic radiographs resulting from changes in patient head position rotating the head inferiorly and superiorly beginning with Frankfurt horizontal plane parallel with the floor using a human skull with guide wires to simulate the long axis of teeth. The more distal the position of the tooth in the arch the greater the change in mesiodistal axial inclination with a change in vertical head position. The mandibular anterior teeth displayed inconsistencies in the direction and pattern of mesiodistal axial inclination change with corresponding alterations of head position. A superior head tilt produced a greater change in mesiodistal axial inclination than did an inferior head tilt. Hardy et al concluded accurately taken panoramic radiographs can serve as a convenient tool for evaluating the mesiodistal axial inclination of teeth before, during, and after orthodontic treatment and recommend additional radiographs for the assessment of mandibular anterior inclinations.
More recently, Peck et al utilized CBCT for comparison with panoramic images prior to orthodontic treatment in five subjects to determine whether panoramic projection can accurately determine mesiodistal root angulations. There were statistically significant differences in 75% of the measurements. The maxillary anterior roots were overinclined in a mesial direction and the posterior roots were overinclined in a distal direction on the panoramic projections. The largest deviation from the CBCT measurements was between the maxillary canines and the first premolars, where the average angular difference was 10°. This creates an illusion that there is exaggerated root divergence between these teeth. The inclination for the mandibular anterior roots was not bilaterally symmetrical, whereas the trend for the mandibular posterior roots was for mesial inclination. The first premolars show the largest mesial inclinations of the mandibular teeth. They concluded panoramic images did not accurately represent the mesiodistal root angulations on clinical patients based on comparisons to CBCT reconstructed panoramic images.

**Cone Beam Computed Tomography (CBCT)**

With the introduction of computed tomography (CT) by Sir Godfrey Hounsfield in 1967 there was the potential to provide high quality, accurate 3D images of any anatomic region. CT became commercially available for medical imagining in 1972; however, several limitations have precluded the widespread application of conventional CT in dentistry. Despite increased popularity and improved technology, CT scans still require longer scan times, more expensive equipment, and higher ionizing radiation exposure compared with traditional 2D imaging techniques resulting in only a very specialized niche in dental and maxillofacial imaging. Following its introduction in the late 1990s and FDA approval in 2001, the use of Cone Beam Computed Tomography (CBCT) has been one of
several recent advances in the area of 3D dental imaging.\textsuperscript{31} There are a variety of differences between CT and CBCT. Conventional CT image acquisition is accomplished via rotation of a fan shaped x-ray beam in a spiral pattern from a high output rotating anode generator. The result of a conventional CT scan is a series of axial plane slices that are acquired either from the continuous circular motion over the axial plane, or as a series of stacked slices.\textsuperscript{32} Alternatively, CBCT image acquisition occurs by means of a fixed low-energy anode emitting a cone shaped x-ray beam directed at the subject. In a single revolution, the beam passes 360 degrees around the patient opposed to the multiple revolutions obligatory with conventional CT.

A special image intensifier and sensor is coupled with the cone-shaped beam leading to reduced absorbed dose of radiation to the patient and efficient use of x-ray emission. The radiation exposure dose is significantly different between conventional CT and CBCT. CBCT use for maxillofacial imaging produces an effective dose that is 8-10 times less than a similar conventional CT exam.\textsuperscript{33} A CBCT scan has ionizing radiation exposure to the patient that is between 2 and 4.5 times higher than a lateral cephalometric and panoramic film combined.

The average scan time for image acquisition of a CBCT is between 10-40 seconds and exposure dose is about 50 \(\mu\text{Sv}\). With regard to ionizing radiation exposure, the 150\(\mu\text{Sv}\) associated with a full mouth radiographic examination (D speed film, round collimation) utilizes about 3 times the dose of the New Tom 3G exam.\textsuperscript{34} This dose is equivalent to 4-6 days of per capita background dose.
The image resolution of CBCT is between 0.1-0.5 mm depending on the scanner and its settings. These values are the dimensions in the x, y, and z planes of the smallest element of a 3D image, known as a volume element (voxel).\textsuperscript{35}

The benefit to using CBCT data is the ability to view maxillofacial regions in three dimensions via a digital representation of the patient’s anatomy as it exists in nature (anatomic truth).\textsuperscript{35} This concept represents a definite advantage over traditional 2D views that may be hindered by rotational, geometric, and head positioning errors. These errors may lead to inaccurate representation of anatomic landmarks, or poor visualization of some structures. The problem of necessary image calibration for magnification of the 2D projection is also eliminated with CBCT data. Traditional 2D imaging always yields some level of projection error due to the fact that the anatomic area of interest is some distance from the film onto which the image is being projected. CBCT projections are orthogonal, meaning that the x-ray beams are parallel to one another, and the source to object distance is quite small resulting in very little projection error. The small amount of projection error that does exist is corrected by the CBCT scanner’s software which results in 1 to 1 data.\textsuperscript{32}

The diagnostic data that is acquired for a CBCT scan is not limited to 3D information only. The standard 2D lateral cephalograms and panoramic radiographs orthodontists are familiar analyzing can be created by imaging software directly from the CBCT data. This allows the orthodontist to obtain the traditional 2D images as well as 3D data all from one exposure. The “synthetic” cephalograms created from CBCT have been shown to recreate conventional cephalometric geometry with similar precision and accuracy.\textsuperscript{36,37}

A comparison of panoramic radiographs and CBCT scans at the completion of orthodontic treatment has not been published. Given the advances in three-dimensional
imaging resulting from the implementation of CBCT, the present investigation seeks to evaluate the suitability and accuracy of panoramic images for evaluation of axial tooth inclinations as post-treatment root parallelism is an important objective at completion of orthodontic treatment for both normal occlusion and stability.
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INTRODUCTION

During orthodontic treatment, the alignment of the roots of the teeth in parallel axial inclinations is critical for the correct alignment and occlusion of the teeth and in maintaining a stable orthodontic result. Panoramic radiographs have, traditionally, been used as a diagnostic aid before, during and after orthodontic treatment to assess root position. Indeed, the clinical examination portion of the American Board of Orthodontics certification requires the submission of panoramic radiographs for documentation of root inclination and parallelism at the completion of treatment.¹

Unfortunately, because panoramic image generation necessitates large beam deviations from the perpendicular to the object and film, tooth position and inclination can be distorted and/or magnified by varying amounts during acquisition. Numerous investigators have evaluated angular distortion within panoramic images, especially with regard to tooth inclination. These investigations have demonstrated panoramic images have limits when utilized for the assessment of mesiodistal angulations.²⁻⁸ Angular distortion within the radiograph results from the combined, variable distortion in the horizontal and vertical dimensions.⁸ The angulations measured from panoramic images relative to known angulations have demonstrated significant alterations in the mesiodistal angulations for the majority of maxillary and mandibular teeth.²⁻⁵,⁹
Cone beam computed tomography (CBCT) of the craniofacial complex provides the opportunity to evaluate patient anatomy, including the occlusion and tooth angulations, in three-dimensions. Peck et al. utilized CBCT for comparison with panoramic images prior to orthodontic treatment in five subjects. The angulations measured from the panoramic images were different from those based on CBCT reconstructed panoramic images and the standard panoramic images produced a false impression of mesial tilt on maxillary anterior teeth and distal tilt on maxillary posterior teeth but there was no recognizable pattern in the mandible. The conclusion was that the CBCT values were more accurate given that CBCT reconstructions do not have the distortions inherent in the two dimensional panoramic radiograph acquisition. The purpose of this project was to compare the mesiodistal root angulations measured from post-treatment panoramic radiographic images and CBCT volumes, rather than reconstructed panoramic images. Study participants had completed orthodontic treatment and orthognathic surgery and received concurrent panoramic radiographs and NewTom CBCT scans at the end of the post-surgical orthodontic phase of treatment (approximately one year after surgery).

MATERIALS AND METHODS

Study subjects were obtained from a review of the clinical records of 157 subjects who had consented to participate in an ongoing prospective observational project (NIH grant, Influences on Stability following Orthognathic Surgery) between July 21, 2003 and May 1, 2008, the project was approved by the Biomedical Institutional Review Board. Each subject signed a consent form (assent with parental permission) as well as a HIPAA consent for use of clinical records. The inclusion criteria were 1) concurrent panoramic and CBCT images taken at the end of the post-surgical phase of orthodontics (approximately 1 year after
(surgery) and 2) a panoramic radiograph obtained using Sirona Orthophos XG Plus (Sirona Dental Systems, Charlotte, NC). Subjects were excluded if 1 or more dilacerated root per quadrant were present due to difficulty in determining long axis of tooth or if more than 1 tooth per quadrant anterior to the 1st molar were missing.

Each subject was assigned a random identification number so that measurements made on the panoramic radiographs and CBCT scans would be blinded. Panoramic images were captured via a charge-coupled device image sensor and were imported to the VixWin (Gendex Dental Systems, Des Plains, IL) software package for measurement (Figure 1). CBCT scans were obtained in DICOM (Digital Imaging and Communications in Medicine) format using the NewTom 3G (AFP Imaging, Elmsford, NY) and were accessed using InvivoDental 3D Version 4.1 (Anatomage Inc., San Jose, CA) imaging software to allow measurements (Figure 2).

The mesiodistal root angulations were measured from the 1st molar anteriorly for all teeth in the maxilla and mandible. All measurements were made using the occlusal plane as the reference line. The occlusal plane was constructed in the panoramic image by connecting the cusp tips of all teeth and in the CBCT volume by orienting the occlusal plane parallel to the lower border of the display window from all views. The long axis of the tooth was determined to complete each angular measurement relative to the occlusal plane. In the CBCT volume and panoramic radiograph, the long axis of the tooth was defined by the buccal cusp tip or midpoint of incisal edge and root apex for single rooted teeth and the occlusal aspect of the buccal groove and depth of the bifurcation or trifurcation for multi-rooted teeth. In the CBCT volume, custom sections were created from the axial slice and each measurement was performed from a facial view of the tooth in the posterior. For CBCT
measurements of anterior teeth, the volume rendering was re-oriented to view the tooth from the facial and a custom section was created from the sagittal slice prior to measurement of the tooth.

_Intraexaminer Reliability_

Ten subjects were randomly selected. The measurement procedures (importing the images and measurement) were repeated with one week between the initial and the replicate measurements. Reliability and systematic bias were assessed separately for the panoramic and CBCT images using intraclass correlation statistic and paired t-test, respectively.

_Analysis_

Descriptive statistics were used to summarize the data. An intercept-only linear regression for correlated data with an unstructured covariance structure was used to assess the differences in mesiodistal root angulations between the panoramic images and CBCT scans and whether that difference was related to the jaw or tooth location.

RESULTS

The clinical records of 157 subjects who had consented to participate in an ongoing prospective observational project (NIH grant, Influences on Stability following Orthognathic Surgery) between July 21, 2003 and May 1, 2008 were reviewed. Two subjects did not have CBCT scans present within the clinical record, 118 subjects were imaged with a panoramic machine other than the Sirona Orthophos XG Plus, and an additional two subjects were excluded due to multiple missing teeth or dilacerated roots in one quadrant resulting in a total of 35 subjects in the sample (Figure 3). Approximately 54% of the subjects were female and 83% Caucasian with an average age of 21.2 ± 6.5 years.
The intraclass correlation coefficient for the measurements obtained from the panoramic radiographs ranged from 0.98 to 1.0 and from 0.99 to 1.0 for the CBCT measurements indicating excellent intra-observer reliability. None of the mean differences for the replicate CBCT measurements were statistically significant \( (P>0.05) \). The mean differences for the replicate panoramic angulations for UR3, UR6, and UL2 were statistically significantly different \( (P<0.05) \) from zero; however, none of the mean differences were greater than 0.5°.

The global test for the mean differences between the panoramic and CBCT angulations for both the maxillary and mandibular arches were statistically significant \( (p < 0.0001) \). There was no clear pattern for the differences within either arch (Table 1, 2) although the differences between the panoramic and CBCT angulations were statistically significantly different for all maxillary anterior teeth. There were statistically significant differences in the mesiodistal tooth angulation for 75% of maxillary and 67% of mandibular teeth.

Prior investigations have indicated that variations up to 5° in mesiodistal tooth angulation relative to an established reference plane do not alter treatment decisions during the assessment of tooth angulation on a panoramic radiograph.\(^5.7.11.12\) Application of these clinically significant tolerance limits indicate 34% of maxillary and 38% of mandibular image angles from panoramic radiographs were clinically significantly different from angles represented in the CBCT volume when evaluated on a tooth by tooth basis (Figure 4).

**DISCUSSION**

The majority of orthodontists utilize mid-treatment panoramic radiographs to evaluate axial tooth inclination to either reposition brackets or place detailing bends in the archwire to
enhance axial tooth position. An understanding of anticipated deviations in axial tooth position represented by the panoramic radiograph is important clinically. Previous investigations have indicated significant inaccuracy in mesiodistal tooth angulations as represented by panoramic radiographs. These studies have attributed the inaccuracy of panoramic images to projection geometry, focal trough depth and geometry, variable vertical and horizontal magnification factors, and patient positioning errors.\(^2,5,13-17\) Although there is potential for image distortion due to a slight wobble during unit rotation in CBCT image acquisition, a correction algorithm within the software removes the distortion prior to image reconstruction. The accuracy of a CBCT volume is typically only limited by resolution or pixel size.\(^18-20\) Several studies have verified the accuracy of measurements from CBCT image volumes with the majority focusing on linear measurements.\(^18,20,21\) Additionally, Marmulla\(^19\) et al concluded the digital volume tomographies of NewTom 9000 provide images which are geometrically correct and Mischkowski\(^22\) et al concluded the CBCT device (GALILEOS) provides acceptable information about linear distances and volumes. This study was undertaken to assess the deviation in axial inclination depicted by panoramic radiographs compared to CBCT volumes in a sample of patients at the conclusion of orthodontic treatment to identify panoramic errors that could be expected at the completion of treatment.

The results of this investigation indicated that most panoramic image angulations were statistically significantly different from the angulations represented in the CBCT volume. For clinical purposes, it has been established by previous investigators that variations over 5° between a tooth and an established reference plane create significant changes during the assessment of tooth angulation on a panoramic radiograph.\(^5,7,11,12\)
Application of these clinically significant tolerance limits indicated that 43% of maxillary anterior, 24% of maxillary posterior, 39% of mandibular anterior and 36% of mandibular posterior image angles from panoramic radiographs were clinically significantly different from the angles represented in the CBCT volume.

The direction of the differences between mesiodistal tooth angulations on the panoramic radiographs and CBCT when assessing all teeth, except the maxillary first molars, indicated that the following teeth demonstrated exaggerated mesial root tip on the panoramic radiograph: maxillary lateral incisors and canines and mandibular premolars while the remaining teeth exhibited exaggerated distal root tip. However, the only area where statistically significant differences were observed on both the right and left sides of the dental arch was in the maxillary anterior region. For all maxillary anterior teeth, the panoramic image demonstrated exaggerated distal root tip for the central incisors and exaggerated mesial root tip for the lateral incisors and canines. The exaggeration of mesial root tip for maxillary lateral incisors and canines is in agreement with previous investigations which have recognized overinclination in the mesial direction for all maxillary anterior teeth from panoramic images. The findings regarding central incisor angulation was opposite that reported by McKee et al and Peck.3,10 Although statistically significant differences were not obtained bilaterally for the maxillary posterior teeth, the directionality of the differences was the same for 1st and 2nd premolars with both exhibiting exaggerated distal root tip on the panoramic image relative to the CBCT volume. This finding supports the presence of overstated root divergence between maxillary canines and first premolars previously reported.3,9,10
Although the statistically significant differences between the two images on the right and left sides were not consistent in the mandible, the directional pattern of the differences indicate exaggerated distal root tip of central incisors, lateral incisors, canines and first molars and exaggerated mesial root tip in the premolar region on the panoramic images relative to the CBCT volume. These results contradict those of McKee et al who found exaggerated mesial inclination of the roots with the largest discrepancy between lateral incisors and canines where root parallelism was misrepresented as root convergence. The current investigation indicates the greatest discrepancy occurred between the two images for the canines and 1st premolar with exaggerated root convergence in this region on the panoramic image.

The panoramic radiograph is frequently utilized by the clinician during treatment to evaluate and adjust the mesiodistal tooth angulation. The risk is that a change of inclination of the teeth in the buccolingual direction can appear as a change in mesiodistal tooth angulation. Increased lingual root torque frequently appears as more mesial root tip on the panoramic image while increased buccal root torque results in more distal root tip. The effect of a buccolingual angulation on the mesiodistal angulation is inconsistent and extensive variability has been reported.²⁹

Although the current investigation utilized conventional slices and custom sections for the measurement of mesiodistal tooth inclination, the three-dimensional renderings of the CBCT volume may provide a more powerful and simplified tool for the visualization of root angulation and proximity by the clinician rather than making assessments using the conventional slices. However, the three-dimensional renderings were not an effective tool
for the measurement of mesiodistal tooth inclination due to difficulty in accurately selecting points within the volume and localizing points for measurement within the same plane.

The method of image acquisition for the current study may have introduced an increased variability in the panoramic radiographs measurements. Panoramic radiographs were obtained by trained dental assistants within the Radiology clinic as a part of an ongoing prospective observational project which also included a CBCT volume and a cephalometric radiograph. The panoramic radiographs were captured utilizing one of five panoramic units housed in the Radiology clinic at UNC but only those obtained using the Sirona OrthoPhos XG Plus were included in this study. Other panoramic units were excluded due to difficulty in ascertaining which images were acquired with particular units and the limited numbers of images attributable to specific panoramic units. Therefore, the results of this study relate only to the particular panoramic unit utilized. McKee et al. indicate a similar pattern of deviations in mesiodistal tooth angulations compared to known angulations for four different units when panoramic radiographs were obtained in a standardized position. The investigators included a prior generation of the Sirona unit used in the present investigation (Orthophos) and reported results comparable to the other three units (OP100 [Instrumentarium; Tuusula, Finland], Cranex 3+ [Orion Soredex; Helsinki, Finland], PM 2002 EC Proline [Planmeca; Helsinki, Finland]). The variability in personnel and lack of a standard protocol for using a specific unit in the ongoing prospective observational project may have increased the likelihood of patient positioning errors since the technicians were required to utilize multiple panoramic units and may have developed varying degrees of comfort with each unit. Previous investigations indicate a great degree of variability and significant differences in panoramic image axial tooth inclinations when patient positioning
is varied.\textsuperscript{2,6,13,12} Ludlow\textsuperscript{18} et al indicated that patient positioning difficulties associated with panoramic images are not present in CBCT images when assessing hard tissue. However, it has been suggested soft tissue assessment may be altered by patient positioning as some CBCT units require a supine rather than seated position for image acquisition.

**CONCLUSIONS**

- The panoramic radiograph remains an excellent screening instrument for the evaluation of present and missing or supernumerary teeth, dental age and eruption sequence. However, the panoramic image provides less reliable information regarding mesiodistal tooth angulations and may exhibit deviations in both mesial and distal directions for all teeth.

- When utilizing the panoramic radiograph for the assessment of mesiodistal tooth angulation throughout treatment, the radiographic data must be combined with a thorough intraoral evaluation to produce the most satisfactory results.

- The advent of CBCT produces the opportunity for clinicians to obtain three-dimensional images of the craniofacial complex with similar absorbed dose to existing dental radiographs and the three-dimensional volume renderings provide a powerful tool for the visualization of root angulation.
REFERENCES


Figure 1. Panoramic measurement via VixWin

Figure 2. CBCT measurement via InvivoDental
**Figure 3. Subject Selection Flow Chart**

- **157 subjects**
  - From Ongoing prospective observational project
- **155 subjects**
  - Remaining
- **37 subjects**
  - Remaining
- **35 subjects**
  - Final Sample Size
- **2 subjects**
  - Missing CBCT volume
- **118 subjects**
  - Panoramic Image not from Orthophos XG Plus
- **2 subjects**
  - Multiple Dilacerated Roots in same quadrant

**Figure 4. Clinically Significant Deviations by Arch and Location**

- **Mx Anterior**
  - Significant MRT: 38.9%
  - Clinically Acceptable: 9.1%
  - Significant DRT: 15.1%
- **Mx Posterior**
  - Significant MRT: 57.2%
  - Clinically Acceptable: 3.8%
- **Mnd Anterior**
  - Significant MRT: 61.1%
  - Clinically Acceptable: 5.8%
  - Significant DRT: 33.2%
- **Mnd Posterior**
  - Significant MRT: 63.7%
  - Clinically Acceptable: 17.6%
  - Significant DRT: 18.7%
Table 1. Maxillary Descriptive Statistics and Linear Regression

<table>
<thead>
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<th>Tooth</th>
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* Pan – CBCT values – Positive values indicate greater distal inclination on panoramic image relative to CBCT volume
Table 2. Mandibular Descriptive Statistics and Linear Regression

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