# Reliability of Digital Dental Cast Measures as Compared to Cone-Beam Computed Tomography for Analyzing the Transverse Dimension

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# RELIABILITY OF DIGITAL DENTAL CAST MEASURES AS COMPARED TO CONE-BEAM COMPUTED TOMOGRAPHY FOR ANALYZING THE TRANSVERSE DIMENSION

by

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ABSTRACT

# RELIABILITY OF DIGITAL DENTAL CAST MEASURES AS COMPARED TO CONE-BEAM COMPUTED TOMOGRAPHY FOR ANALYZING THE TRANSVERSE DIMENSION

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The purpose of this study was to assess the consistency in diagnosing the transverse dimension on cone-beam computed tomography (CBCT) images as compared to digital dental models.

The study consisted of 11 patients with posterior crossbite at the level of the first molar and 17 patients with no crossbite at the level of the first molar. 13 patients were male and 15 patients were female with an overall mean age of 13.6 years. Eight linear measurements and two angular measurements were made on CBCT images of the patients and six linear measurements were made on the corresponding digital dental casts. CBCT and model measurements were compared using One-Way Analysis of Variance (ANOVA) and Pearson correlation tests were used to seek relationships between the dental and skeletal measurements on CBCT.

All ratios between maxillary and corresponding mandibular measurements were larger in non-crossbite patients than in crossbite patients. The central fossa (CF) was found to be the most representative and reliable tooth measurement in judging dental and skeletal transverse dimensions. A normative CF-CF ratio was determined to be equal to or greater than 1.10 for non-crossbite patients. High correlations were found between dental and skeletal measurements for non-crossbite patients with a CF-CF ratio equal to or greater than 1.10, but were not found for crossbite patients with a CF-CF ratio less than 1.10.

In conclusion, CBCT scans may not provide additional diagnostic information as compared to dental models for non-crossbite patients. However, CBCT scans may be diagnostically beneficial for crossbite patients. Further studies with a larger sample size are needed to determine the validity of this study.

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# LIST OF ABBREVIATIONS

2D: two-dimensional

3D: three-dimensional

ABO: American Board of Orthodontics

ANOVA: analysis of variance

CBCT: cone-beam computed tomography

CEJ: cemento-enamel junction

CF: central fossa

CVMS: cervical vertebral maturation stage

DB: distobuccal

DL: distolingual/distopalatal

ICC: intraclass correlation coefficient

MB: mesiobuccal

ML: mesiolingual/mesiopalatal

PA: posterior-anterior

RME: rapid maxillary expansion

TWM: transpalatal width measurement

# INTRODUCTION

Orthodontics is a dental specialty focusing on the correction of malocclusions. A malocclusion is defined as a problem in the way the upper and lower teeth are aligned or fit together during biting or chewing. Dr. Edward Angle, who is considered the father of modern orthodontics, was the first to classify this term and based his definition on the first permanent molar relationship, as its position remained constant following eruption (Angle, 1899). One of the most common types of malocclusion is a posterior crossbite. A posterior crossbite is a problem in the transverse dimension, and occurs when the upper posterior teeth are lingual to their normal position, the lower posterior teeth are buccal to their normal position, or both. The root of this type of problem may be dental or skeletal in nature, and it is the responsibility of the orthodontist to correctly identify the source in order to properly treat (Proffit et al., 2013).

Conventionally, a posterior crossbite could only be diagnosed from dental models. The dental diagnosis is still being used by the American Board of Orthodontics (ABO) as its way of judging the skeletal transverse relationship between the maxilla and mandible. These methods, however, are obviously not reflective of any skeletal transverse problems. The advent of cone-beam computed tomography (CBCT) radiographs has enabled orthodontists to accurately evaluate the dentition and the underlying skeleton in all three dimensions. Such technology has made the accurate diagnosis of problems like posterior crossbite much more likely. Miner et al. developed a transverse analysis based on CBCT radiographs to help orthodontists diagnose posterior crossbites (Miner et al. 2012, 2015). While their analysis was relatively thorough, they called for further studies to accurately measure basal bone dimensions as well as assess the transverse dimension in patients with various sagittal discrepancies.

Based on the previous studies (Miner et al.), the purpose of this study was to test whether a dental crossbite coincides with a skeletal transverse discrepancy, or if not, the likelihood a dental crossbite can represent a skeletal transverse discrepancy.

# REVIEW OF LITERATURE

Posterior crossbite is one of the most common malocclusions to affect the deciduous and mixed dentitions. It is defined as an abnormal buccolingual relationship of a posterior tooth or teeth of the maxilla, mandible, or both when the teeth of the two arches are in occlusion and it may be unilateral or bilateral (Wood, 1962). The current research suggests the frequency of posterior crossbite to range from 7% to 22% of cases (Day and Foster, 1971; Thilander and Myrberg, 1973; Troelstrup and Moller, 1979; Egermark-Eriksson et al., 1990; da Silva Filho et al., 2007; Borzabadi-Farahani et al., 2009; Sidlauskas and Lopatiene, 2009). A unilateral crossbite resulting from a functional shift of the mandible toward the affected side is the most prevalent form of posterior crossbite and accounts for approximately 80% to 97% of all cases (Kutin and Hawes, 1969; Schroder and Schroder, 1984; Thilander et al., 1984; Sidlauskas and Lopatiene, 2009). Cases of skeletal crossbite are due to a discrepancy in the transverse dimension of the maxilla when compared to the mandible. This can result in either a unilateral or bilateral posterior crossbite. Presentations of skeletal crossbite include a narrow maxilla with a normal mandible, a normal maxilla with a wide mandible, or a narrow maxilla with a wide mandible (Betts and Vanarsdall, 1995). In contrast, dental crossbites are usually due to anomalies in tooth size or shape, arch length deficiency, over retained primary teeth, delayed erupting permanent teeth, an abnormal eruption pattern, or tooth ankylosis. (Kutin and Hawes, 1969).

Review of the literature demonstrates a multifactorial etiology of posterior crossbites that includes dental, muscular, and osseous considerations. Though the weight of the effect of each factor has not been proven, constriction of the transverse dimension of the maxilla appears to be the most frequent cause. Non-nutritive sucking habits, such as pacifier or digit-sucking, is a common etiologic factor and leads to the maxillary arch becoming more V-shaped with great constriction at the canine areas (Melsen et al., 1979; Melink et al., 2010; Proffit et al. 2013). One study evaluating children ages zero to six years old with a pacifier-sucking habit found that the prevalence of posterior crossbite was approximately four times as high in these children when compared to children without a pacifier-sucking habit (Ogaard et al., 1994). Further studies ascertained similar results, and found that the later the discontinuation of the habit, especially after the age of four, the higher the prevalence of posterior crossbite. (Adair 2003; Warren et al., 2005; Bishara et al., 2006; Scavone Jr et. al., 2007). Reduction of maxillary width can also be due to swallowing habits, a lower tongue posture, or mouth breathing secondary to upper airway obstruction from adenoid tissues or nasal allergies (Linder-Aronson, 1970; Thilander, et al., 1984; Hannuksela and Vaananen, 1987).

Many studies have shown that spontaneous correction of posterior crossbite is rare. One study found that in 48 untreated cases of bilateral posterior crossbite in the deciduous dentition, only four cases self-corrected upon eruption of the permanent first molars (Kutin and Hawes, 1969). Another study showed that only 17% of unilateral crossbite cases in the mixed dentition spontaneously corrected in the permanent dentition (Lidner, 1989). Other studies have explained that if a crossbite persists, transverse growth will continue to be inhibited and the surrounding musculature will be allowed to adjust to the narrowed dimension. However, if a crossbite is corrected early, the dentition usually develops normally thereafter and often requires no further treatment (Clifford 1971; Schroder and

Schroder, 1984; Kurol and Berglund, 1992; McNamara, 2002). Thus, the literature advocates for early correction of posterior crossbite.

Another reason for the promotion of early treatment of posterior crossbite is to take advantage of the ability to get true orthopedic expansion of the maxilla along a patent midpalatal suture. Because maxillary transverse constriction seems to be the most common cause of posterior crossbite, the ideal treatment should target on this deficiency in maxillary width and orthopedic skeletal expansion has become the treatment of choice. Angell was the first to describe the concept of expanding a maxilla to correct a posterior crossbite by opening the midpalatal suture in the mid-1800's. He described the use of a jackscrew placed on the roof of the mouth of a 14-year-old girl with ends bearing across the first and second premolars from one side to another to correct maxillary transverse constriction (Angell, 1860). The early orthodontic literature included controversy as to whether it was possible to widen the hard palate at the midpalatal suture and suggested the possibility of inducing a serious disturbance in the surrounding hard and soft tissue by this method. However, work by Haas in the 1960's made this novel technique, called rapid maxillary expansion (RME), a common practice in most orthodontic offices after demonstrating successful treatment in 45 human subjects. (Haas, 1961).

RME can be a successful, nonsurgical means for widening the maxilla to correct a posterior crossbite assuming the midpalatal suture is patent. However, like all craniofacial sutures, the midpalatal suture becomes more tortuous and interdigitated with increasing age (**Fig. 1**). Melsen used histology and microradiology to assess the sutural changes in the human palate in subjects aged zero to 18 years old and found that lack of sutural interdigitation in younger children was a major reason for successful, nonsurgical maxillary expansion (Melsen, 1975).

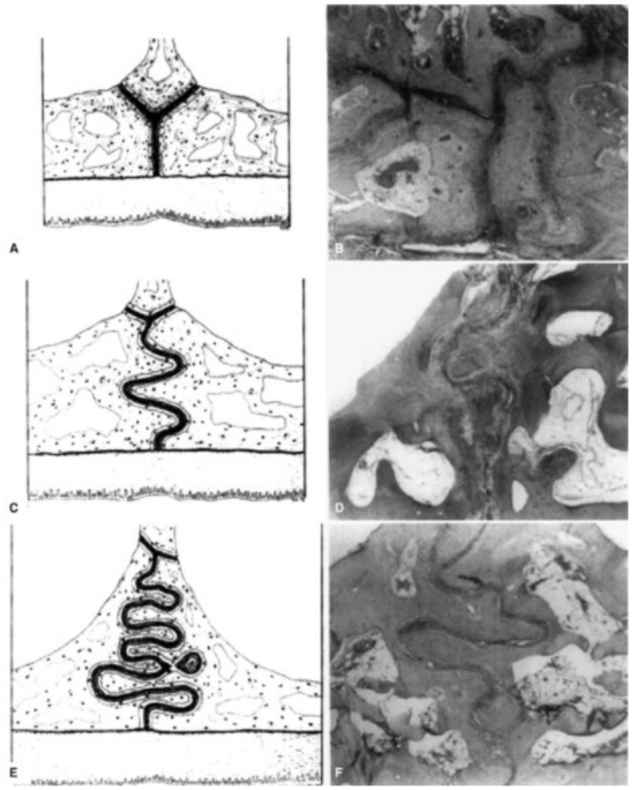


**Fig. 1. Schematic and histological sections depicting increased interdigitation of the midpalatal suture with increased age as presented by Melsen**

Up until the age of ten, almost any type of expansion device will tend to separate the midpalatal suture resulting in mostly orthopedic correction. However, by adolescence, a relatively heavy force is needed to separate the increasingly interdigitated suture (Proffit et al., 2013). In this way, RME can be achieved by using a rigid jackscrew with tooth-tissue borne or tooth-borne fixation to the teeth. Such appliances are capable of separating the suture by producing the necessary heavy forces ranging from 15 to 50 Newtons (Lagravere et al., 2005).

Baccetti et al. examined the effects of RME based on the age of patients at treatment initiation. Looking at the cervical vertebrae maturation stage (CVMS) for each patient, he found that those who had not yet reached the pubertal growth spurt at the onset of RME treatment showed on average 3 mm of expansion of the mid-palatal suture. Those treated after the pubertal growth spurt averaged only 0.9 mm of expansion at the suture. His findings suggested that an effective long-term change at the skeletal level occurs when the patients were treated prior to the pubertal peak growth, but that higher dental effects tended to result if individuals were treated after the pubertal growth spurt. His work also suggested that in order to get true skeletal expansion with minimal dental effects, surgical treatment would be the best option for older patients with ossified or heavily interdigitated midpalatal sutures (Baccetti et al., 2001).

Because of its high prevalence, the long-term implications of not treating, and the significance of timing for successful correction without surgery, posterior crossbites need to be readily and properly diagnosed. While a posterior crossbite is often diagnostic for a constricted maxilla, a narrow maxillary intermolar width without a posterior crossbite can also indicate the need for maxillary expansion (McNamara, 2002). The absence of a crossbite in a patient with a narrow maxilla possibly results from the stability of intermolar width established early and continues to manifest during maxillary and mandibular transverse growth throughout adolescence. In patients with a narrow maxilla but no posterior crossbite, it is common to find dental compensations such as excessive buccal flaring of the maxillary dentition and a deep Curve of Wilson in the lower dentition that mask the maxillary transverse constriction (Kapila, 2014).

The maxillary transpalatal width measurement (TWM) by Howe et al. is the most common analysis in diagnosing the transverse dimension based on dental casts. The TWM is the distance between the cervical midlingual region of the permanent first molars (Howe et al., 1983). The ABO currently uses a similar method by assessing the skeletal transverse dimension of patients based on dental models. In grading the dental models of candidates for board certification, the ABO's reference document states, "Overjet is used to assess the relative transverse relationship of the posterior teeth… In the posterior region, the mandibular buccal cusps and maxillary lingual cusps are used to determine proper position within the fossae of the opposing arch… The overjet is evaluated by articulating the models and viewing the labiolingual relationship of the maxillary arch relative to the mandibular arch." (American Board of Orthodontics, 2012). Multiple studies have demonstrated the accuracy and reliability of digital dental model measurements as compared to those made on plaster models and show no significant differences between the two (Gracco et al., 2007; Sousa et al., 2012; Reuschl et al., 2016). As previously explained, however, the dentition may mask a skeletal transverse deficiency. The TWM can be significantly affected by molar inclination and may not accurately represent the maxillary skeletal dimension. Hence, the use of radiographic images may be necessary to assess these dental compensations and accompanying alveolar boundary conditions.

Traditionally, postero-anterior (PA) cephalograms have been used to assess the transverse dimension of the bony skull, and a number of analyses have emerged to evaluate the breadth, symmetry, morphology, shape, and size of the craniofacial skeleton. (Svanholt and Solow, 1977; Ricketts, 1981; Grummons and Kappeyne van de Coppello, 1987; Athanasiou, 1995). Ricketts' analysis is the most common of these assessments. To measure the transverse discrepancy, Ricketts compared the widths between the right and left jugale points and between the right and left antegonial points (Ricketts, 1981). However, because there is great variation of landmark location due to film-object distance effects, the correlation between these points accounts for only 50% of the variance of the outcome. Therefore, use of this analysis might not be as reliable of an indicator of transverse relationships as previously believed (Ghafari et al., 1995; Huertas and Ghafari, 2001). Another challenge with PA cephalograms is that many structures superimpose on each other which reduces the clarity of the landmarks and increases identification errors (Major et al., 1994). And finally, any rotation of the head around a vertical axis when taking the PA cephalogram affects the horizontal relationships of the landmarks, making it difficult to assess symmetry and measure horizontal distances (Major et al., 1996).

CBCT scans reduce the sources of error that are observed with two-dimensional (2D) cephalograms. Much literature exists that establishes the accuracy of measurement, including that of maxillary transverse measurements, on three-dimensional (3D) radiographs. Fourie et al. took CBCT scans of seven cadaver heads and compared 21 linear measurements made on the CBCT images to those same measurements made on the dried skulls. They found an absolute error of less than 1.5mm for all measurements (Fourie et al., 2011). Gribel et al. conducted a similar study with 25 dry skulls and found no statistically significant difference between CBCT measurements and direct craniometric measurements with a mean difference of 0.1 mm (Gribel et al., 2011). van Vlijmen et al. radiographed 40 dried skulls to generate conventional 2D PA cephalograms and constructed 3D CBCT PA radiographs. They demonstrated the ease of landmark identification and measurement taking on the 3D CBCT image as compared to the 2D PA cephalogram (**Fig. 2**) and assessed the reliability of angular and linear measurements made on each image. Each measurement had a higher reliability rating on the CBCT images compared with the conventional 2D PA cephalograms. The average reliability of angular measurements taken from the right and left jugale points, for example, was approximately 40% higher on the constructed 3D PA cephalogram (van Vlijmen et al., 2009).

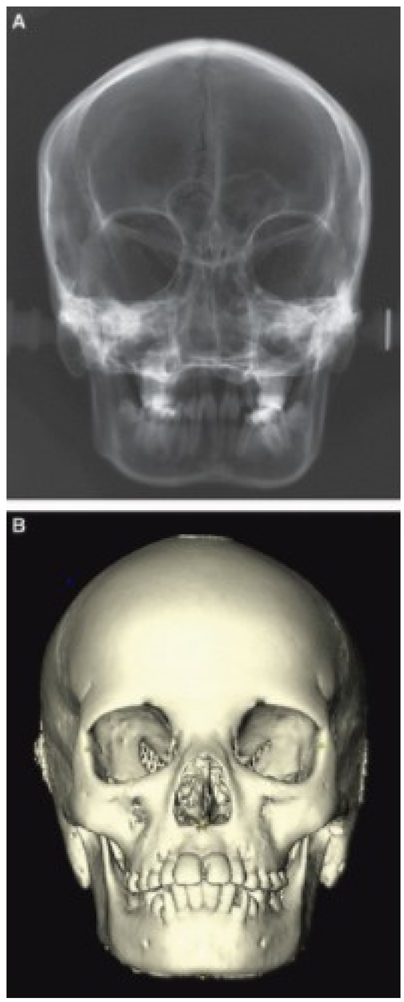


**Fig. 2. Comparison of (A) conventional 2D PA cephalogram and (B) CBCT-constructed 3D model as presented by van Vlijmen et al.**

With its high reliability of making accurate measurements, CBCT has become a valuable resource in enhancing orthodontic diagnosis and treatment. Miner et al. used CBCT to formulate an original analysis of the transverse dimension to aid orthodontists in their diagnoses. Examining CBCT scans, they came up with a range of normal positions and relationships between the maxillary and mandibular molars and its related skeleton. They found that a significant number of patients in the clinical non-crossbite group had a skeletal transverse jaw discrepancy that had been masked by dental compensation. In addition, they derived normative values for the skeletal and dental measurements for the CBCT transverse analysis from the control group, which was defined by having molar inclinations of all first molars within one standard deviation above or below the mean of the non-crossbite group. They concluded that patients without crossbites can have significant discrepancies that might warrant treatment. Because all the patients used by Miner et al. had a molar Class I relationship, they called for future studies to evaluate the transverse dimension in patients with varying sagittal molar relationships. The landmarks used in their study could not eliminate the effect of tooth position on skeletal width, so they also called for future research to focus on an accurate representation of basal bone (Miner et al., 2012, 2015).

These previous studies (Miner et al.), however, have obvious shortcomings. Firstly, their measurements and normal values were derived from their study sample which does not represent all populations, either normal without crossbite or patients with crossbite. And secondly, even within their study sample, using linear distances to define a skeletal transverse discrepancy is not appropriate due to the anatomical variations of each individual.

Therefore, based on the identified gaps in knowledge and shortcomings of previous studies (Miner et al.), the purpose of this study was to judge the consistency in diagnosing the transverse dimension in patients with and without crossbite, and provide an accurate transverse assessment of basal bone. Additionally, to test the reliability of the ABO's use of dental casts to measure the skeletal transverse dimension, this study compared the transverse measurements made on digital dental casts with those acquired from CBCT images. The null hypothesis was that there is no difference in diagnosis of the skeletal transverse dimension between dental models and CBCT images.

# MATERIALS AND METHODS

The CBCT scans and digital dental models of 72 patients were examined from the Department of Orthodontics at Marquette University School of Dentistry in Milwaukee, Wisconsin. All scans and models were reviewed retrospectively. The university's institutional review board reviewed and approved this research (#HR-3300) prior to data collection.

The included patients were those with quality maxillary and mandibular jaw CBCT images and complete digital dental models. Exclusion criteria were incomplete records, low quality images not fully displaying the maxilla and mandible, previous orthodontic treatment, craniofacial anomalies or trauma, obvious skeletal asymmetries, and systemic disease.

28 patients met the inclusion and exclusion criteria with a mean age of 13.6 years (range, 9.6-18.4 years). 13 patients were male and 15 patients were female. 11 patients presented with a posterior crossbite at the first molar level (7 bilateral and 4 unilateral) and 17 patients had no crossbite at the first molar level (although, 3 had bilateral posterior crossbites and 2 had unilateral crossbites at other tooth levels). All CBCT scans were taken by one certified radiologist (L.K.) at the Radiology Department at Marquette University, using a Scanora 3D device (Soredex, Tuusula, Finland). These images were evaluated and analyzed in the InVivoDental Application imaging software (version 5.3.3; Anatomage, San Jose, California). The dental models were acquired by the orthodontic residents in the Department of Orthodontics at Marquette University School of Dentistry. Alginate impressions were taken and poured up with orthodontic plaster. Models were

then scanned into e-model (version 8.6, GeoDigm Corporation, Falcon Heights, Minnesota) for observation and analysis.

Because the patients had varying sagittal dental relationships, the CBCT images were oriented separately for maxillary and mandibular measurements at the first molar level. For maxillary measurements, the long-axis of the maxillary right first molar was oriented perpendicular to the image horizontal in the sagittal plane (**Fig. 3**). The long-axis of the maxillary first molar in the sagittal plane was defined as a line drawn between the deepest concavity between the buccal and palatal cusps and the furcation of the roots. The mesial height of contour of the right and left maxillary first molars were oriented parallel to the image horizontal in the axial plane (**Fig. 4**). The inferior tip of the right and left medial pterygoid plates were oriented level to the image horizontal in the coronal plane. The slice for maxillary measurements was taken at the depth of the furcation of the maxillary right first molar as viewed in the sagittal plane.

CBCT images for mandibular measurements were oriented in a similar fashion as the maxillary images. The long-axis of the mandibular right first molar was oriented perpendicular to the image horizontal in the sagittal plane. The long-axis of the mandibular first molar in the sagittal plane was defined as a line drawn between the deepest concavity between the buccal and palatal cusps and the furcation of the roots. The mesial height of contour of the right and left mandibular first molars were oriented parallel to the image horizontal in the axial plane. The inferior tip of the right and left medial pterygoid plates were oriented level to the image horizontal in the coronal plane. The slice for mandibular measurements was taken at the depth of the furcation of the mandibular right first molar as viewed in the sagittal plane.

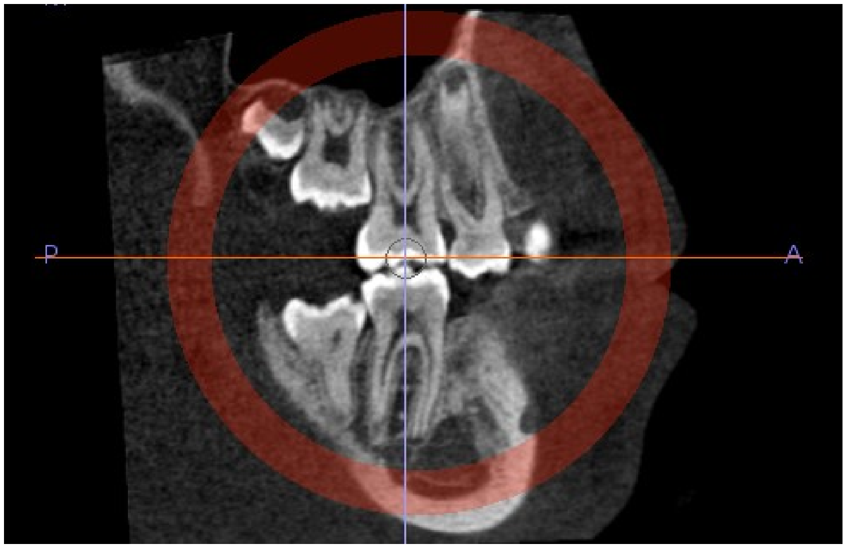


**Fig. 3 Orientation of the long-axis of the maxillary right first molar perpendicular to the image horizontal in the sagittal plane**

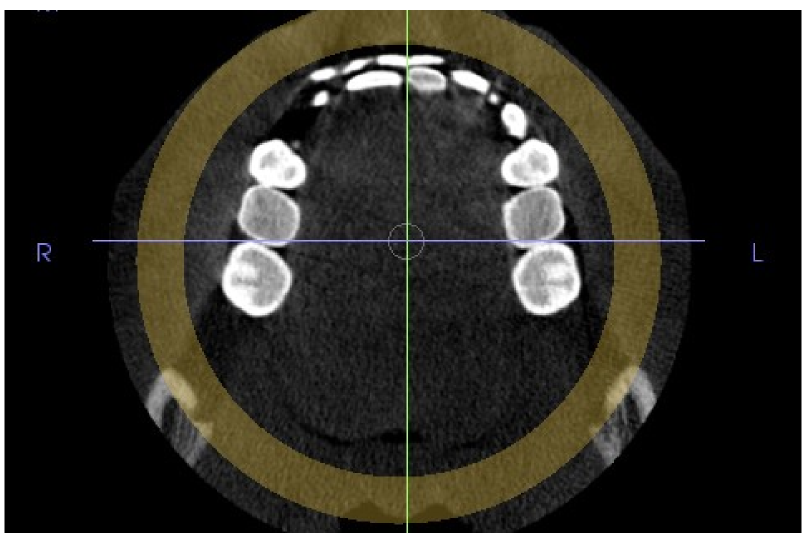


**Fig. 4. Orientation of the mesial height of contour of the right and left maxillary first molars parallel to the image horizontal in the axial plane**

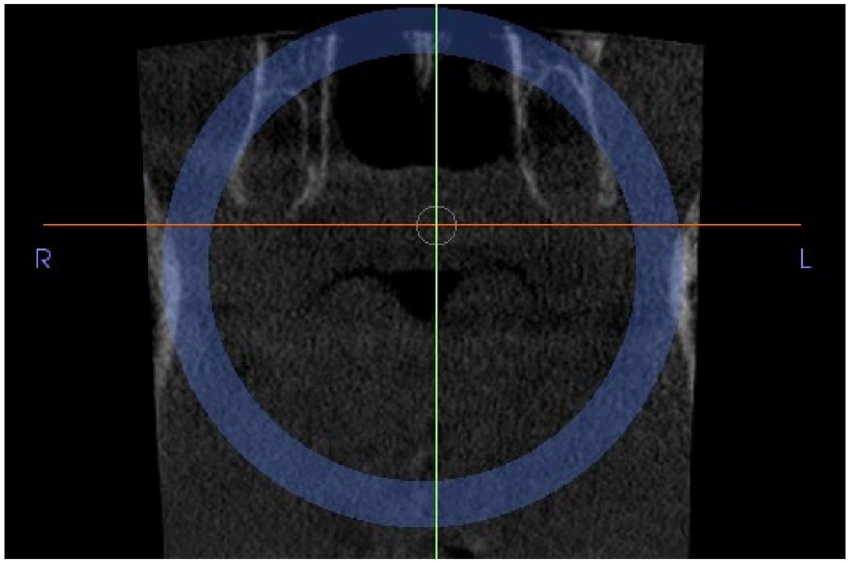


**Fig. 5. Orientation of the inferior tip of the right and left medial pterygoid plates level to the image horizontal in the coronal plane**

Eight linear measurements and two angular measurements were made in the maxilla and mandible of separately oriented CBCT slices in the coronal plane. These landmarks and parameters are defined in **Table 1**. The linear measurements were made between the first molars at the following landmarks: central fossa (CF) (**Fig. 6**), buccal cusp tip **(Fig. 7**), lingual/palatal cusp tip (**Fig. 8**), lingual cemento-enamel junction (CEJ) (**Fig. 9**), furcation (**Fig. 10**), buccal alveolar bone at first molar furcation level (**Fig. 11**), lingual or palatal alveolar bone at first molar furcation level (**Fig. 12**), and buccal basal bone at first molar root apex level (**Fig. 13**). Additionally, the internal angle of the long-axis of the right and left maxillary and mandibular first molars to the occlusal plane was measured (**Fig. 14**). The long-axis of the maxillary first molar in the coronal plane was defined as a line drawn between the deepest concavity between the buccal and palatal cusps and the furcation of the roots. The long-axis of the mandibular first molar in the coronal plane was defined as a line drawn between the deepest concavity between the buccal and palatal cusps and the root apex. The occlusal plane was defined separately for the maxillary and mandibular slices due to differences in anteroposterior dental relationships among patients and due to some patients being imaged with their mandible in a partially open position. The occlusal plane was defined as a plane passing from lingual cusp tip to lingual cusp tip of the maxillary first molars for maxillary CBCT slices and from central fossa to central fossa of the mandibular first molars for mandibular CBCT slices. These landmarks were used because they are opposing centric contacts in normal Class I occlusion in the absence of a dental crossbite and are the landmarks through which Miner et al. traced the functional occlusal plane (Miner et al., 2012). These landmarks were used regardless of the presence or absence of a dental crossbite in the patient.

**Table 1. Dental and skeletal landmarks and parameters for CBCT measurements made on slices in the coronal view**

| *Landmark or parameter* | *Definition* |
|---|---|
| Central fossa (CF) | The deepest concavity between the buccal and lingual/palatal cusps |
| Buccal cusp tip | The most occlusal point of the buccal cusp |
| Lingual/palatal cusp tip | The most occlusal point of the lingual/palatal cusp |
| Lingual/palatal cemento-enamel junction (CEJ) | The most apical point of the enamel on the lingual/palatal surface |
| Furcation | The deepest concavity between roots |
| Buccal alveolar bone at first molar furcation level | Points on the buccal cortical plates bilaterally bisected by a line drawn through the first molar furcations |
| Lingual/palatal alveolar bone at first molar furcation level | Points on the lingual/palatal cortical plates bilaterally bisected by a line drawn through the first molar furcations |

| | |
|---|---|
| Buccal bone at first molar root apex level (basal bone) | Points on the buccal cortical plates bilaterally bisected by a line drawn through the most apical first molar root apices |
| Long-axis of maxillary first molar | The line drawn between the deepest concavity between the buccal and palatal cusps and the furcation of the roots |
| Long-axis of mandibular first molar | The line drawn between the deepest concavity between the buccal and palatal cusps and the root apex |
| Occlusal plane (maxilla) | The line passing from palatal cusp tip to palatal cusp tip of the maxillary first molars |
| Occlusal plane (mandible) | The line passing from central fossa to central fossa of the mandibular first molars |
| Internal angle of first molars | The angle formed medially between the long-axis of the first molar and the occlusal plane |


**Fig. 6. Measurement between central fossaes of maxillary first molars on a coronal CBCT image**

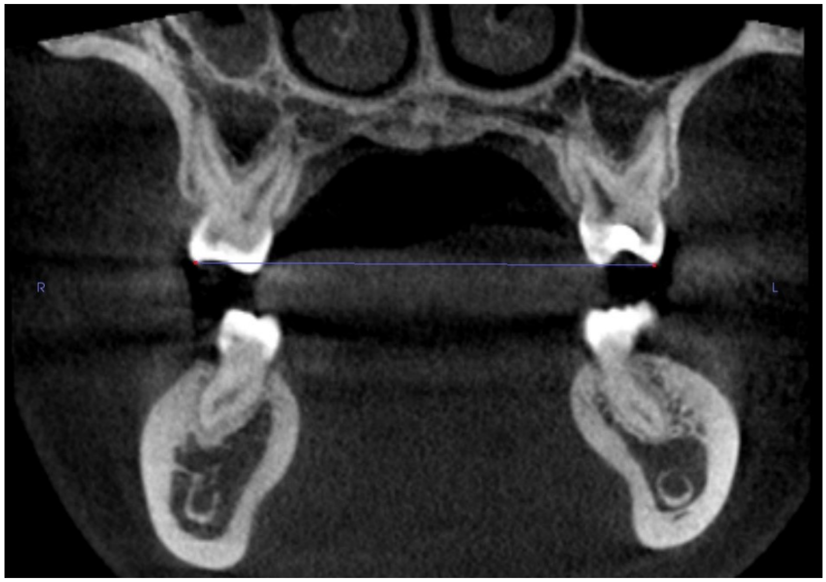


**Fig. 7. Measurement between buccal cusps of maxillary first molars on a coronal CBCT image**

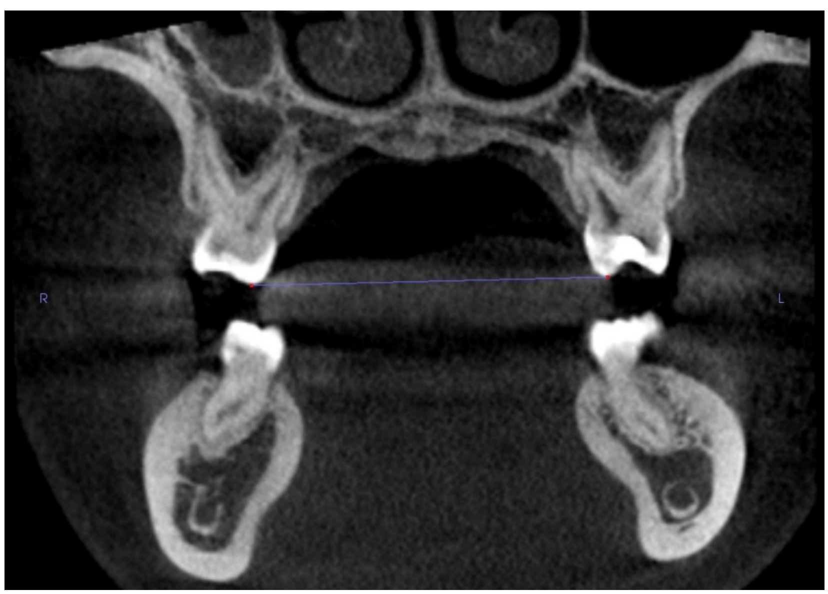


**Fig. 8. Measurement between lingual cusps of maxillary first molars on a coronal CBCT image**

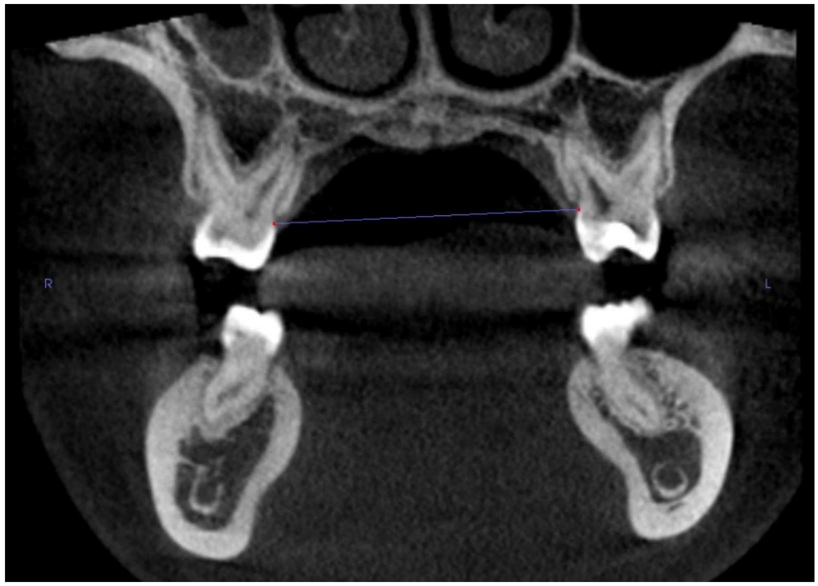


**Fig. 9. Measurement between lingual cemento-enamel junctions of maxillary first molars on a coronal CBCT image**


**Fig. 10. Measurement between the depths of furcations of maxillary first molars on a coronal CBCT image**


**Fig. 11. Measurement between buccal bone at the level of the maxillary first molar furcations on a coronal CBCT image**

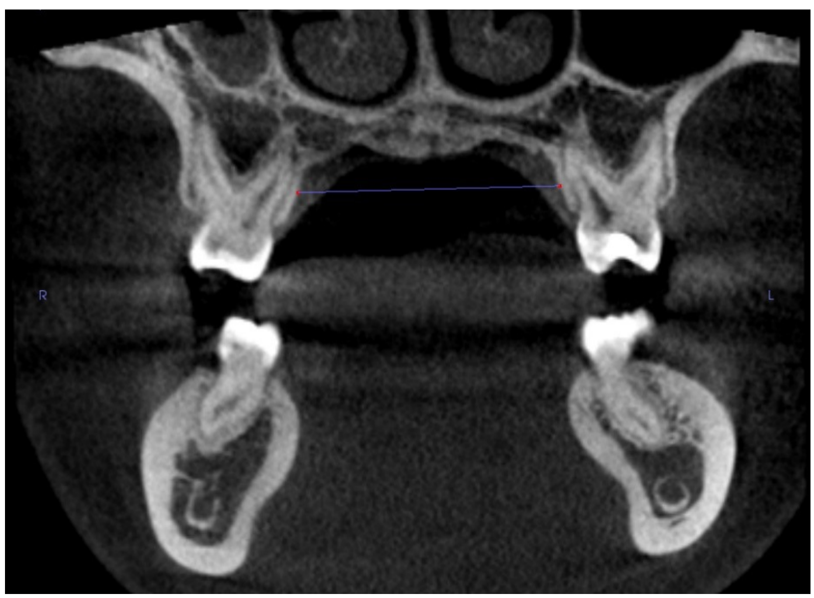


**Fig. 12. Measurement between palatal bone at the level of the maxillary first molar furcations on a coronal CBCT image**

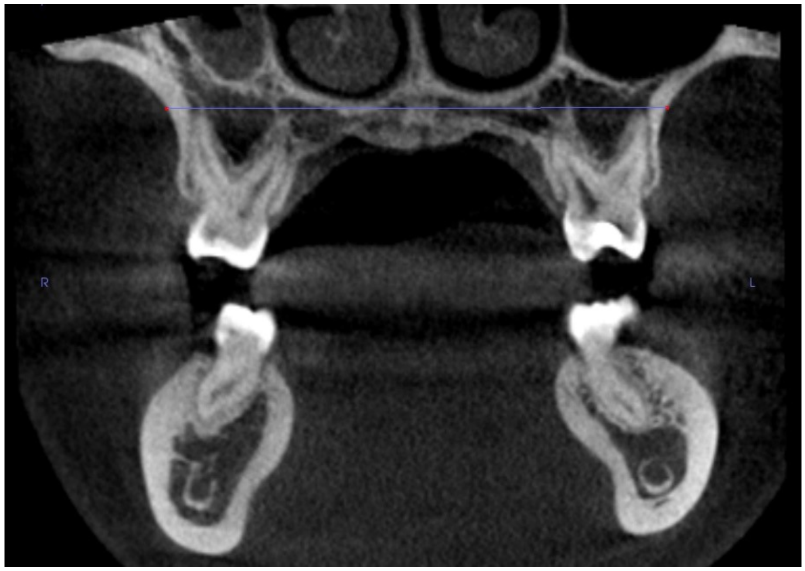


**Fig. 13. Measurement between basal bone at the level of the most apical maxillary first molar root apices on a coronal CBCT image**

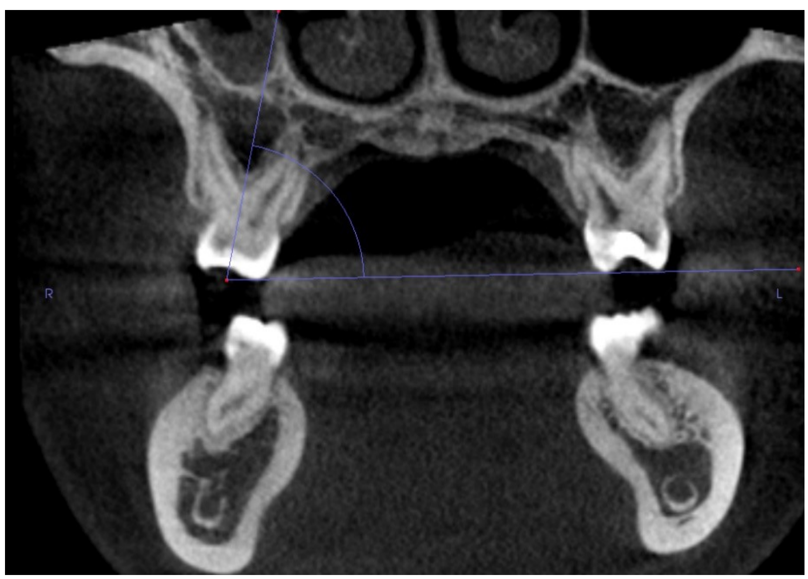


**Fig. 14. Measurement of the angle of the long-axis of the maxillary right first molar to the occlusal plane on a coronal CBCT image**

Six linear measurements were made on the maxillary and mandibular digital dental casts. These landmarks and parameters are defined in **Table 2**. The measurements were made between the first molars at the following landmarks: central fossa (**Fig. 15**), mesiobuccal (MB) cusp tip (**Fig. 16**), distobuccal (DB) cusp tip (**Fig. 17**), mesiopalatal/mesiolingual (ML) cusp tip (**Fig. 18**), distopalatal/distolingual (DL) cusp tip (**Fig. 19**), and palatal/lingual CEJ at the narrowest points (**Fig. 20**).

**Table 2. Dental landmarks and parameters for digital dental model measurements**

| *Landmark or parameter* | *Definition* |
|---|---|
| Central fossa (CF) | The deepest concavity between the buccal and lingual/palatal cusps at the central pit |
| Mesiobuccal cusp tip (MB) | The most occlusal point of the mesiobuccal cusp |
| Distobuccal cusp tip (DB) | The most occlusal point of the distobuccal cusp |
| Mesiopalatal/mesiolingual cusp tip (ML) | The most occlusal point of the mesiopalatal/mesiolingual cusp |
| Distopalatal/distolingual cusp tip (DL) | The most occlusal point of the distopalatal/distolingual cusp |
| Lingual/palatal cemento-enamel junction (CEJ) | The most medial point on the lingual/palatal surface at the free gingival margin |

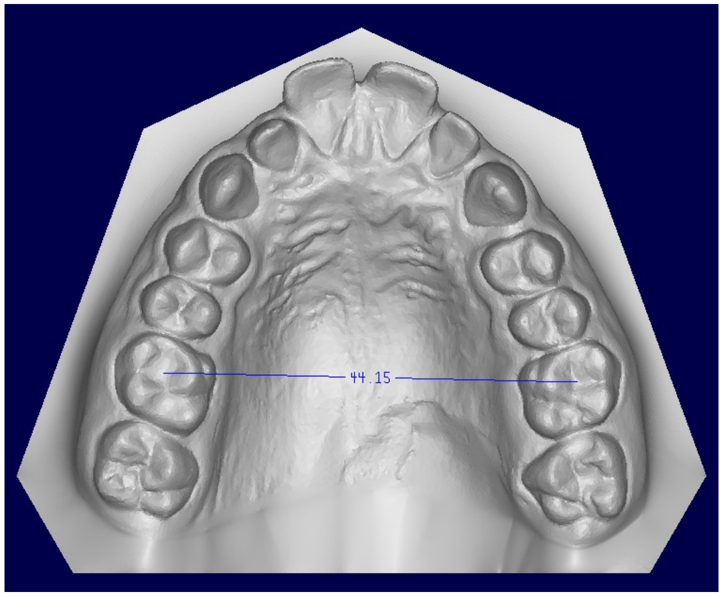


**Fig. 15. Measurement between central fossaes of maxillary first molars on a digital dental model**

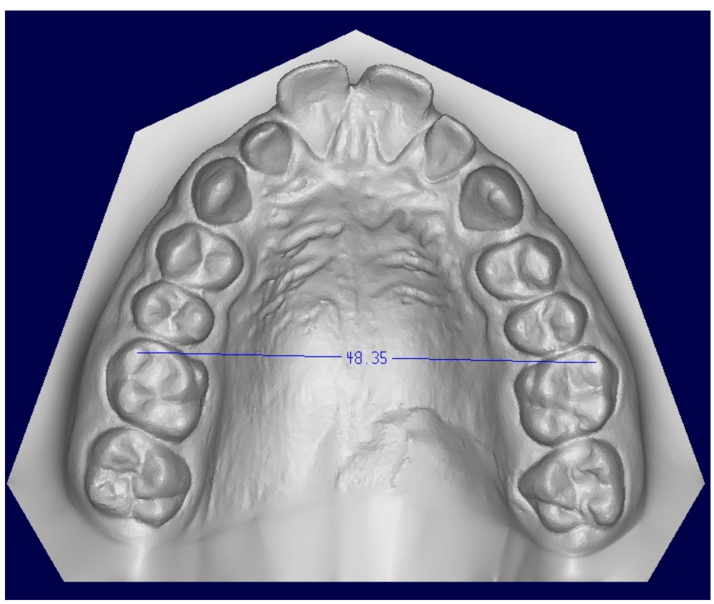


**Fig. 16. Measurement between mesiobuccal cusp tips of maxillary first molars on a digital dental model**

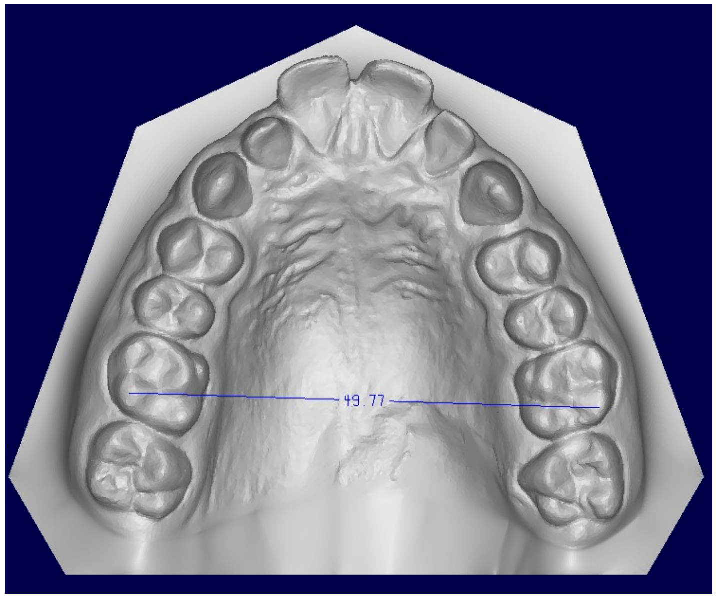


**Fig. 17. Measurement between distobuccal cusp tips of maxillary first molars on a digital dental model**

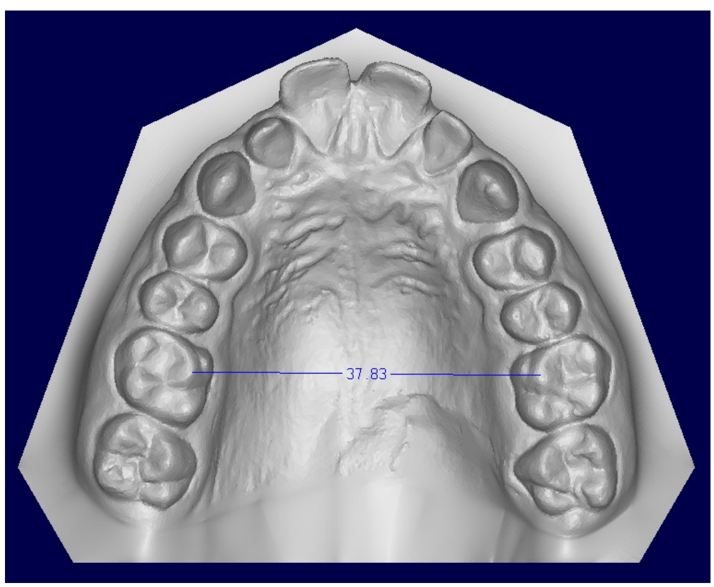


**Fig. 18. Measurement between mesiopalatal cusp tips of maxillary first molars on a digital dental model**

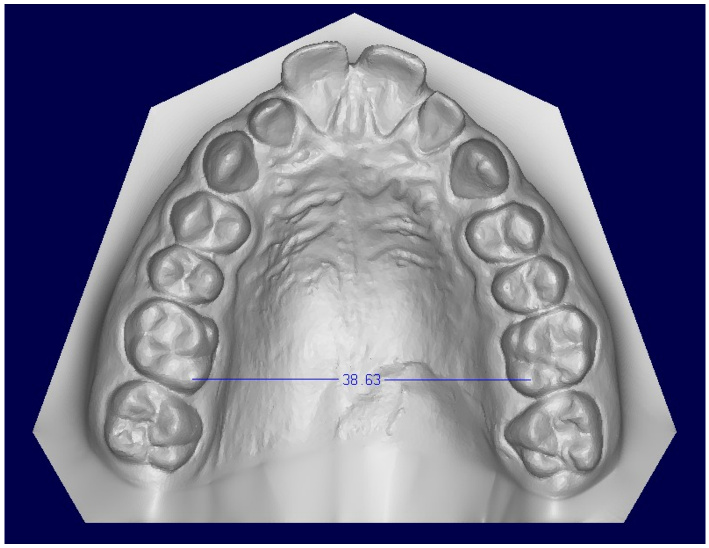


**Fig. 19. Measurement between distopalatal cusp tips of maxillary first molars on a digital dental model**

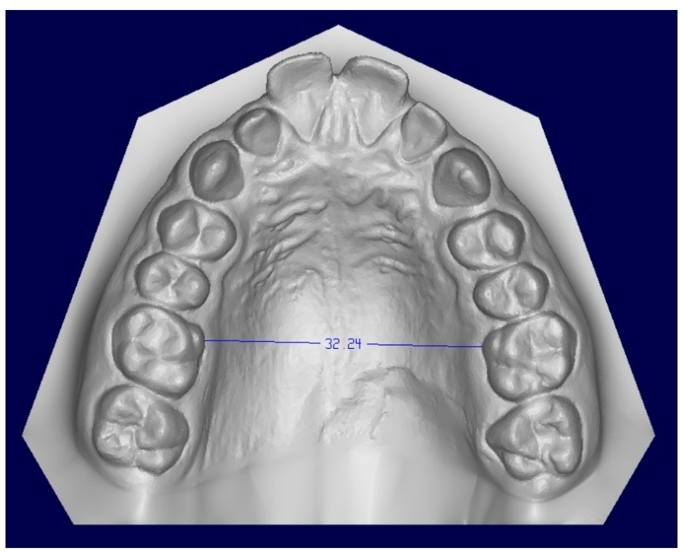


**Fig. 20. Measurement between the lingual cemento-enamel junctions of maxillary first molars on a digital dental model**

The measurements were made by utilizing the measurement tools provided within the corresponding software. All measurements were performed by one of the investigators (B.M.). For the CBCT measurements, this investigator was trained and calibrated to identify 3D landmarks on axial, sagittal and coronal planes by a certified radiologist (L.K.).

Statistical Analysis

All statistics were performed using IMB SPSS Statistics 23. To improve accuracy, all measurements were repeated for three random patients at three time points with three days separating the time points and the means were used for comparison. Intra-rater reliability was tested with Intraclass Correlation Coefficient (ICC) for each model and CBCT measurement. Chi-Square and One-Way Analysis of Variance (ANOVA) tests were used to check demographic homogeneity between those clinically determined to be with and without crossbite at the first molar.

ANOVAs were used to compare model and CBCT crown measurements against one another, and to compare model and CBCT crown measurements of those clinically determined to be with and without crossbite at the level of the first molar against one another. Type I error was controlled by using Bonferroni corrections within the model measurements and the CBCT measurements.

After checking the linearity of relationships by scatter-plot, correlations were used to seek redundancies among the CBCT crown and among the CBCT bone measurements. After checking the linearity of relationships by scatter-plot, correlations were used to seek relationships between the CBCT tooth and bone measurements. For significant (or borderline significant) CBCT tooth-bone relationships, predictors were by (linear) curve estimation. All statistical analyses were performed by Ms. Katie Sherman (statistician at Marquette University).

# RESULTS

The intra-rater reliability showed no variation in measurements over time on both the model and CBCT measurements with an overall mean ICC of 0.959 and over. Descriptive statistics for all measurements are listed in **Table 3** as ratios between measurements made on the maxilla vs. mandible.

Cross-comparisons were made between the following groupings: gender, ethnicity, right first molar sagittal classification, and left first molar sagittal classification. These comparisons are listed in **Tables 4 through 7**, respectively. No significant differences were found, which suggests that any further comparisons were not likely to be influenced by how the patients were grouped. Age cross-comparisons were made using a one-way ANOVA as seen in **Table 8**. A borderline significance was found that suggests that non-crossbite patients may be older than crossbite patients.

Differences in measurements between model and CBCT were tested based on the following three measurements: CF, MB (model) or buccal cusp (CBCT), and CEJ. These tests can be seen in **Table 9**. No significant differences existed between model and CBCT measurements of CF and MB. CEJ measurements, however, showed a significant difference, with the model means higher and model standard deviations lower compared to CBCT.

Ratio comparisons of measurements for the maxilla and mandible on both model and CBCT by non-crossbite vs. crossbite were tested based on the same three measurements: CF, MB (model) or buccal cusp (CBCT), and CEJ. These tests can be seen in **Table 10**. Significant differences were found between non-crossbite and crossbite patients for these ratios using both model and CBCT for $p < 0.05$ (Type 1 not controlled) and $p < 0.01$ (Type 1 controlled within 5 tests of model ... see **Table 11** for the other 2 tests) and $p < 0.005$ (Type 1 controlled within 10 tests of CT ... see **Table 12** for the other 7 tests). The non-crossbite means were larger for these ratios, and the crossbite standard deviations were larger except for CEJ.

**Table 11** contains the other two tests for model measurements by non-crossbite and crossbite patients. Ratio comparisons were made between maxilla CF and mandible MB, as well as maxilla ML and mandible CF. Significant differences were found for these measurements between non-crossbite and crossbite patients using $p < 0.05$ (Type 1 not controlled) and $p < 0.01$ (Type 1 controlled within 5 tests of model ... see **Table 10** for the other 3 tests). The non-crossbite means were larger for these ratios, and the crossbite standard deviations were higher.

**Table 12** contains the other seven tests for CBCT measurements by non-crossbite and crossbite patients. Ratio comparisons were made between maxilla and mandible for the following measurements: furcation, buccal cusp tip, buccal alveolar bone at first molar furcation level, lingual or palatal alveolar bone at first molar furcation level, buccal basal bone at first molar root apex level, right first molar angulation and left first molar angulation. Significant differences were found between non-crossbite and crossbite patients for furcation, buccal cusp tip, and buccal alveolar bone at first molar furcation level given a $p < 0.05$ (Type 1 not controlled) and $p < 0.005$ (Type 1 controlled within 10 tests of CT ... see **Table 10** for other 3 tests), and lingual or palatal alveolar bone at first molar furcation level and buccal basal bone at first molar root apex level given a $p < 0.05$ (Type 1 not controlled). There was no significant difference for the tooth angulations. For all cases where there was significance, the non-crossbite means were higher. For all cases where there was significance, except for the furcation measurement, the crossbite standard deviations were higher.

Statistical tests were conducted to explore the relationships among the different measurements from the CBCT. The tests for tooth measurements can be seen in **Table 13** and bone measurements in **Table 14**. Because CBCT and model measurements of similar structures showed no significant difference (see **Table 9**), the model measurements were ignored. The results of these correlation tests showed that CF and ML were redundant, CF and MB were nearly redundant, and MB and ML were highly related. The best tooth measurement was shown to be CF, as it best represented the other tooth measurements ($p < 0.01$). No redundancies existed among bone measurements, therefore no bone measurements could be removed from consideration in the further analyses. All bone measurements except lingual alveolar bone at furcation level and basal bone at apical level were moderately or highly linearly related (and significant for $p < 0.01$).

**Table 15** shows the maxillary vs. mandibular CF-CF ratio for all patients. Among the non-crossbite patients, a CF-CF ratio on model and CBCT of equal to or greater than 1.10 appeared to be the standard. All crossbite patients presented with a CF-CF ratio less than 1.10. Correlation between the tooth measurements and bone measurements were then tested based on this proposed ratio. **Table 16** shows the correlation testing for patients with a CF-CF ratio of 1.10 or greater. A very strong relationship existed between CF and buccal bone at furcation level ($p < 0.01$). Strong relationships existed between CF and furcation as well as CF and lingual/palatal bone at furcation level. ($p < 0.01$ and 0.05, respectively). There was a borderline significant relationship that is a strong relationship between CF and basal bone as well as CF and CEJ. **Table 17** shows the correlation testing for patients with a CF-CF ratio of less than 1.10. A very strong relationship existed between CF and furcation as well as CF and buccal bone at furcation level ($p < 0.01$ and 0.05, respectively). No relationship existed between CF and lingual/palatal bone at furcation level nor between CF and basal bone.

**Table 3. Descriptive statistic ratios between maxilla and mandible for all measurements**

| | N | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| age | 28 | 9.6 | 18.4 | 13.643 | 2.1876 |
| Model ratio maxilla ML to mandible CF | 28 | .77 | 1.02 | .9288 | .06639 |
| Model ratio maxilla CF to mandible DB | 28 | .78 | 1.01 | .9365 | .05868 |
| Model ratio maxilla CF to mandible CF | 28 | .88 | 1.19 | 1.0727 | .07207 |
| Model ratio maxilla CEJ to mandible CEJ | 28 | .77 | 1.09 | .9854 | .08042 |
| Model ratio maxilla MB to mandible MB | 28 | .95 | 1.20 | 1.1052 | .06567 |
| CBCT ratio maxilla furcation to mandible furcation | 28 | .77 | 1.05 | .9166 | .06775 |
| CBCT ratio maxilla buccal cusp to mandible buccal cusp | 28 | .92 | 1.20 | 1.0976 | .07127 |
| CBCT ratio maxilla buccal bone to mandible buccal bone | 28 | .778 | 1.146 | .96582 | .082159 |
| CBCT ratio maxilla right molar angle to mandible right molar angle | 28 | .60 | 1.02 | .7761 | .09368 |
| CBCT ratio maxilla left molar angle to mandible left molar angle | 28 | .55 | .95 | .7807 | .08020 |
| CBCT ratio maxilla CEJ to mandible CEJ | 28 | .78 | 1.06 | .9366 | .07322 |
| CBCT ratio maxilla lingual bone to mandible lingual bone | 28 | .63 | 1.12 | .8723 | .12030 |
| CBCT ratio maxilla basal bone to mandible basal bone | 28 | .72 | 1.12 | .9149 | .08995 |
| CBCT ratio maxilla CF to mandible CF | 28 | .92 | 1.17 | 1.0851 | .07156 |
| CBCT ratio maxilla MB to mandible MB | 28 | .92 | 1.20 | 1.0976 | .07127 |
| CBCT ratio maxilla ML to mandible ML | 28 | .93 | 1.26 | 1.1506 | .09291 |
| CBCT ratio maxilla CF to mandible CF >= 1.1 (FILTER) | 28 | 0 | 1 | .54 | .508 |

**Table 4. Gender cross-comparisons**

| | | | group | | Total |
|---|---|---|---|---|---|
| | | | Non-Crossbite | Crossbite | |
| gender | F | Count | 9 | 6 | 15 |
| | | % within gender | 60.0% | 40.0% | 100.0% |
| | | % within group | 52.9% | 54.5% | 53.6% |
| | | % of Total | 32.1% | 21.4% | 53.6% |
| | M | Count | 8 | 5 | 13 |
| | | % within gender | 61.5% | 38.5% | 100.0% |
| | | % within group | 47.1% | 45.5% | 46.4% |
| | | % of Total | 28.6% | 17.9% | 46.4% |
| Total | | Count | 17 | 11 | 28 |
| | | % within gender | 60.7% | 39.3% | 100.0% |
| | | % within group | 100.0% | 100.0% | 100.0% |
| | | % of Total | 60.7% | 39.3% | 100.0% |

Chi-Square Tests

| | Value | df | Asymptotic Significance (2-sided) | Exact Sig. (2-sided) | Exact Sig. (1-sided) |
|---|---|---|---|---|---|
| Pearson Chi-Square | .007[a] | 1 | .934 | | |
| Continuity Correction[b] | .000 | 1 | 1.000 | | |
| Likelihood Ratio | .007 | 1 | .934 | | |
| Fisher's Exact Test | | | | 1.000 | .620 |
| N of Valid Cases | 28 | | | | |

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 5.11.
b. Computed only for a 2x2 table

**Table 5. Ethnicity cross-comparisons**

| | | | group | | Total |
|---|---|---|---|---|---|
| | | | Non-Crossbite | Crossbite | |
| ethnic | A* | Count | 2 | 0 | 2 |
| | | % within ethnic | 100.0% | 0.0% | 100.0% |
| | | % within group | 11.8% | 0.0% | 7.1% |
| | | % of Total | 7.1% | 0.0% | 7.1% |
| | AA** | Count | 6 | 0 | 6 |
| | | % within ethnic | 100.0% | 0.0% | 100.0% |
| | | % within group | 35.3% | 0.0% | 21.4% |
| | | % of Total | 21.4% | 0.0% | 21.4% |
| | C*** | Count | 7 | 9 | 16 |
| | | % within ethnic | 43.8% | 56.3% | 100.0% |
| | | % within group | 41.2% | 81.8% | 57.1% |
| | | % of Total | 25.0% | 32.1% | 57.1% |
| | H**** | Count | 2 | 2 | 4 |
| | | % within ethnic | 50.0% | 50.0% | 100.0% |
| | | % within group | 11.8% | 18.2% | 14.3% |
| | | % of Total | 7.1% | 7.1% | 14.3% |
| Total | | Count | 17 | 11 | 28 |
| | | % within ethnic | 60.7% | 39.3% | 100.0% |
| | | % within group | 100.0% | 100.0% | 100.0% |
| | | % of Total | 60.7% | 39.3% | 100.0% |

* Asian
** African American
*** Caucasian
**** Hispanic

Chi-Square Tests

| | Value | df | Asymptotic Significance (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | 7.299[a] | 3 | .063 |
| Likelihood Ratio | 10.045 | 3 | .018 |
| N of Valid Cases | 28 | | |

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is .79.

**Table 6. Right first molar sagittal relationship cross-comparisons**

| | | | group | | |
|---|---|---|---|---|---|
| | | | Non-Crossbite | Crossbite | Total |
| R_Molar_Class | Class I | Count | 7 | 6 | 13 |
| | | % within R_Molar_Class | 53.8% | 46.2% | 100.0% |
| | | % within group | 41.2% | 54.5% | 46.4% |
| | | % of Total | 25.0% | 21.4% | 46.4% |
| | Class II | Count | 7 | 3 | 10 |
| | | % within R_Molar_Class | 70.0% | 30.0% | 100.0% |
| | | % within group | 41.2% | 27.3% | 35.7% |
| | | % of Total | 25.0% | 10.7% | 35.7% |
| | Class III | Count | 3 | 2 | 5 |
| | | % within R_Molar_Class | 60.0% | 40.0% | 100.0% |
| | | % within group | 17.6% | 18.2% | 17.9% |
| | | % of Total | 10.7% | 7.1% | 17.9% |
| Total | | Count | 17 | 11 | 28 |
| | | % within R_Molar_Class | 60.7% | 39.3% | 100.0% |
| | | % within group | 100.0% | 100.0% | 100.0% |
| | | % of Total | 60.7% | 39.3% | 100.0% |

Chi-Square Tests

| | Value | df | Asymptotic Significance (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | .620[a] | 2 | .734 |
| Likelihood Ratio | .628 | 2 | .730 |
| N of Valid Cases | 28 | | |

a. 3 cells (50.0%) have expected count less than 5. The minimum expected count is 1.96.

**Table 7. Left first molar sagittal relationship cross-comparisons**

| | | | group | | Total |
|---|---|---|---|---|---|
| | | | Non-Crossbite | Crossbite | |
| L_Molar_Class | Class I | Count | 10 | 5 | 15 |
| | | % within L_Molar_Class | 66.7% | 33.3% | 100.0% |
| | | % within group | 58.8% | 45.5% | 53.6% |
| | | % of Total | 35.7% | 17.9% | 53.6% |
| | Class II | Count | 4 | 4 | 8 |
| | | % within L_Molar_Class | 50.0% | 50.0% | 100.0% |
| | | % within group | 23.5% | 36.4% | 28.6% |
| | | % of Total | 14.3% | 14.3% | 28.6% |
| | Class III | Count | 3 | 2 | 5 |
| | | % within L_Molar_Class | 60.0% | 40.0% | 100.0% |
| | | % within group | 17.6% | 18.2% | 17.9% |
| | | % of Total | 10.7% | 7.1% | 17.9% |
| Total | | Count | 17 | 11 | 28 |
| | | % within L_Molar_Class | 60.7% | 39.3% | 100.0% |
| | | % within group | 100.0% | 100.0% | 100.0% |
| | | % of Total | 60.7% | 39.3% | 100.0% |

Chi-Square Tests

| | Value | df | Asymptotic Significance (2-sided) |
|---|---|---|---|
| Pearson Chi-Square | .609[a] | 2 | .738 |
| Likelihood Ratio | .605 | 2 | .739 |
| N of Valid Cases | 28 | | |

a. 4 cells (66.7%) have expected count less than 5. The minimum expected count is 1.96.

**Table 8. Age cross-comparisons**

ANOVA
age

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 17.697 | 1 | 17.697 | 4.126 | .053 |
| Within Groups | 111.512 | 26 | 4.289 | | |
| Total | 129.209 | 27 | | | |

Non-crossbite

| | N | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| age | 17 | 10.3 | 18.4 | 14.282 | 2.2634 |
| Valid N (listwise) | 17 | | | | |

Crossbite

| | N | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| age | 11 | 9.6 | 15.5 | 12.655 | 1.7189 |
| Valid N (listwise) | 11 | | | | |

**Table 9. Measurement comparisons between model and CBCT**

ANOVA

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| CF | Between Groups | .002 | 1 | .002 | .413 | .523 |
| | Within Groups | .279 | 54 | .005 | | |
| | Total | .281 | 55 | | | |
| CEJ | Between Groups | .033 | 1 | .033 | 5.624 | .021 |
| | Within Groups | .319 | 54 | .006 | | |
| | Total | .353 | 55 | | | |
| MB/buccal cusp | Between Groups | .001 | 1 | .001 | .180 | .673 |
| | Within Groups | .260 | 54 | .005 | | |
| | Total | .261 | 55 | | | |

Model

| | N | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| CF | 28 | .88 | 1.19 | 1.0727 | .07207 |
| CEJ | 28 | .77 | 1.09 | .9854 | .08042 |
| MB | 28 | .95 | 1.20 | 1.1046 | .06614 |
| Valid N (listwise) | 28 | | | | |

CBCT

| | N | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| CF | 28 | .92 | 1.17 | 1.0851 | .07156 |
| CEJ | 28 | .78 | 1.06 | .9366 | .07322 |
| Buccal cusp | 28 | .92 | 1.20 | 1.0968 | .07242 |
| Valid N (listwise) | 28 | | | | |

**Table 10. Ratio comparisons on model and CBCT by non-crossbite vs. crossbite patients**

ANOVA

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Model ratio maxilla CF to mandible CF | Between Groups | .104 | 1 | .104 | 73.367 | .000 |
| | Within Groups | .037 | 26 | .001 | | |
| | Total | .140 | 27 | | | |
| Model ratio maxilla CEJ to mandible CEJ | Between Groups | .136 | 1 | .136 | 91.471 | .000 |
| | Within Groups | .039 | 26 | .001 | | |
| | Total | .175 | 27 | | | |
| Model ratio maxilla MB to mandible MB | Between Groups | .080 | 1 | .080 | 56.340 | .000 |
| | Within Groups | .037 | 26 | .001 | | |
| | Total | .116 | 27 | | | |
| CBCT ratio maxilla CEJ to mandible CEJ | Between Groups | .088 | 1 | .088 | 39.903 | .000 |
| | Within Groups | .057 | 26 | .002 | | |
| | Total | .145 | 27 | | | |
| CBCT ratio maxilla CF to mandible CF | Between Groups | .109 | 1 | .109 | 96.503 | .000 |
| | Within Groups | .029 | 26 | .001 | | |
| | Total | .138 | 27 | | | |
| CBCT ratio maxilla buccal cusp to mandible buccal cusp | Between Groups | .096 | 1 | .096 | 60.509 | .000 |
| | Within Groups | .041 | 26 | .002 | | |
| | Total | .137 | 27 | | | |

Non-crossbite

| | N | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| Model ratio maxilla CF to mandible CF | 17 | 1.06 | 1.19 | 1.1217 | .03056 |
| Model ratio maxilla CEJ to mandible CEJ | 17 | .96 | 1.09 | 1.0414 | .03364 |
| Model ratio maxilla MB to mandible MB | 17 | 1.09 | 1.20 | 1.1481 | .03134 |
| CBCT ratio maxilla CEJ to mandible CEJ | 17 | .89 | 1.06 | .9816 | .04965 |
| CBCT ratio maxilla CF to mandible CF | 17 | 1.09 | 1.17 | 1.1352 | .02143 |
| CBCT ratio maxilla buccal cusp to mandible buccal cusp | 17 | 1.09 | 1.20 | 1.1446 | .02792 |
| Valid N (listwise) | 17 | | | | |

Crossbite

| | N | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| Model ratio maxilla CF to mandible CF | 11 | .88 | 1.05 | .9971 | .04664 |
| Model ratio maxilla CEJ to mandible CEJ | 11 | .77 | .94 | .8987 | .04532 |
| Model ratio maxilla MB to mandible MB | 11 | .95 | 1.09 | 1.0389 | .04588 |
| CBCT ratio maxilla CEJ to mandible CEJ | 11 | .78 | .93 | .8671 | .04202 |
| CBCT ratio maxilla CF to mandible CF | 11 | .92 | 1.07 | 1.0075 | .04690 |
| CBCT ratio maxilla buccal cusp to mandible buccal cusp | 11 | .92 | 1.09 | 1.0248 | .05362 |
| Valid N (listwise) | 11 | | | | |

**Table 11. Centric contact ratio comparisons on model by non-crossbite vs. crossbite patients**

ANOVA

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Model ratio maxilla ML to mandible CF | Between Groups | .086 | 1 | .086 | 66.784 | .000 |
| | Within Groups | .033 | 26 | .001 | | |
| | Total | .119 | 27 | | | |
| Model ratio maxilla CF to mandible MB | Between Groups | .068 | 1 | .068 | 72.713 | .000 |
| | Within Groups | .024 | 26 | .001 | | |
| | Total | .093 | 27 | | | |

Non-crossbite

| | N | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| Model ratio maxilla ML to mandible CF | 17 | .93 | 1.02 | .9733 | .02295 |
| Model ratio maxilla CF to mandible MB | 17 | .95 | 1.01 | .9763 | .02100 |
| Valid N (listwise) | 17 | | | | |

Crossbite

| | N | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| Model ratio maxilla ML to mandible CF | 11 | .77 | .93 | .8601 | .04992 |
| Model ratio maxilla CF to mandible MB | 11 | .78 | .93 | .8750 | .04175 |
| Valid N (listwise) | 11 | | | | |

**Table 12. Ratio comparisons on CBCT by non-crossbite vs. crossbite patients**

ANOVA

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| CBCT ratio maxilla furcation to mandible furcation | Between Groups | .051 | 1 | .051 | 18.357 | .000 |
| | Within Groups | .073 | 26 | .003 | | |
| | Total | .124 | 27 | | | |
| CBCT ratio maxilla buccal cusp to mandible buccal cusp | Between Groups | .096 | 1 | .096 | 60.509 | .000 |
| | Within Groups | .041 | 26 | .002 | | |
| | Total | .137 | 27 | | | |
| CBCT ratio maxilla buccal bone to mandible buccal bone | Between Groups | .063 | 1 | .063 | 13.822 | .001 |
| | Within Groups | .119 | 26 | .005 | | |
| | Total | .182 | 27 | | | |
| CBCT ratio maxilla right molar angle to mandible right molar angle | Between Groups | .003 | 1 | .003 | .327 | .572 |
| | Within Groups | .234 | 26 | .009 | | |
| | Total | .237 | 27 | | | |
| CBCT ratio maxilla left molar angle to mandible left molar angle | Between Groups | .007 | 1 | .007 | 1.036 | .318 |
| | Within Groups | .167 | 26 | .006 | | |
| | Total | .174 | 27 | | | |
| CBCT ratio maxilla lingual bone to mandible lingual bone | Between Groups | .060 | 1 | .060 | 4.722 | .039 |
| | Within Groups | .331 | 26 | .013 | | |
| | Total | .391 | 27 | | | |
| CBCT ratio maxilla basal bone to mandible basal bone | Between Groups | .039 | 1 | .039 | 5.715 | .024 |
| | Within Groups | .179 | 26 | .007 | | |
| | Total | .218 | 27 | | | |

Non-crossbite

| | N | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| CBCT ratio maxilla furcation to mandible furcation | 17 | .80 | 1.05 | .9510 | .05814 |
| CBCT ratio maxilla buccal cusp to mandible buccal cusp | 17 | 1.09 | 1.20 | 1.1446 | .02792 |
| CBCT ratio maxilla buccal bone to mandible buccal bone | 17 | .90 | 1.15 | 1.0041 | .06360 |
| CBCT ratio maxilla right molar angle to mandible right molar angle | 17 | .60 | .91 | .7678 | .08075 |
| CBCT ratio maxilla left molar angle to mandible left molar angle | 17 | .55 | .89 | .7683 | .07918 |
| CBCT ratio maxilla lingual bone to mandible lingual bone | 17 | .63 | 1.08 | .9095 | .10469 |
| CBCT ratio maxilla basal bone to mandible basal bone | 17 | .77 | 1.12 | .9451 | .08923 |
| Valid N (listwise) | 17 | | | | |

Crossbite

| | N | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| CBCT ratio maxilla furcation to mandible furcation | 11 | .77 | .92 | .8634 | .04309 |
| CBCT ratio maxilla buccal cusp to mandible buccal cusp | 11 | .92 | 1.09 | 1.0248 | .05362 |
| CBCT ratio maxilla buccal bone to mandible buccal bone | 11 | .78 | 1.00 | .9067 | .07367 |
| CBCT ratio maxilla right molar angle to mandible right molar angle | 11 | .65 | 1.02 | .7888 | .11387 |
| CBCT ratio maxilla left molar angle to mandible left molar angle | 11 | .68 | .95 | .7998 | .08169 |
| CBCT ratio maxilla lingual bone to mandible lingual bone | 11 | .64 | 1.12 | .8147 | .12463 |
| CBCT ratio maxilla basal bone to mandible basal bone | 11 | .72 | .94 | .8683 | .07191 |
| Valid N (listwise) | 11 | | | | |

**Table 13. Correlation tests confirming all tooth measurements on CBCT are redundant**

Correlations

| | | CBCT ratio maxilla CF to mandible CF | CBCT ratio maxilla buccal cusp to mandible buccal cusp | CBCT ratio maxilla lingual cusp to mandible lingual cusp |
|---|---|---|---|---|
| CBCT ratio maxilla CF to mandible CF | Pearson Correlation | 1 | .949** | .962** |
| | Sig. (2-tailed) | | .000 | .000 |
| | N | 28 | 28 | 28 |
| CBCT ratio maxilla buccal cusp to mandible buccal cusp | Pearson Correlation | .949** | 1 | .922** |
| | Sig. (2-tailed) | .000 | | .000 |
| | N | 28 | 28 | 28 |
| CBCT ratio maxilla lingual cusp to mandible lingual cusp | Pearson Correlation | .962** | .922** | 1 |
| | Sig. (2-tailed) | .000 | .000 | |
| | N | 28 | 28 | 28 |

**Correlation is significant at the 0.01 level (2-tailed).

**Table 14. Correlation tests to check for redundancies among bone measurements on CBCT**

**Correlations**

| | | CBCT ratio maxilla furcation to mandible furcation | CBCT ratio maxilla buccal bone to mandible buccal bone | CBCT ratio maxilla CEJ to mandible CEJ | CBCT ratio maxilla lingual bone to mandible lingual bone | CBCT ratio maxilla basal bone to mandible basal bone |
|---|---|---|---|---|---|---|
| CBCT ratio maxilla furcation to mandible furcation | Pearson Correlation | 1 | .788** | .864** | .673** | .528** |
| | Sig. (2-tailed) | | .000 | .000 | .000 | .004 |
| | N | 28 | 28 | 28 | 28 | 28 |
| CBCT ratio maxilla buccal bone to mandible buccal bone | Pearson Correlation | .788** | 1 | .762** | .593** | .645** |
| | Sig. (2-tailed) | .000 | | .000 | .001 | .000 |
| | N | 28 | 28 | 28 | 28 | 28 |
| CBCT ratio maxilla CEJ to mandible CEJ | Pearson Correlation | .864** | .762** | 1 | .683** | .521** |
| | Sig. (2-tailed) | .000 | .000 | | .000 | .005 |
| | N | 28 | 28 | 28 | 28 | 28 |
| CBCT ratio maxilla lingual bone to mandible lingual bone | Pearson Correlation | .673** | .593** | .683** | 1 | .352 |
| | Sig. (2-tailed) | .000 | .001 | .000 | | .066 |
| | N | 28 | 28 | 28 | 28 | 28 |
| CBCT ratio maxilla basal bone to mandible basal bone | Pearson Correlation | .528** | .645** | .521** | .352 | 1 |
| | Sig. (2-tailed) | .004 | .000 | .005 | .066 | |
| | N | 28 | 28 | 28 | 28 | 28 |

**Correlation is significant at the 0.01 level (2-tailed).

**Table 15. CF-CF ratios for non-crossbite and crossbite patients**

| Clinical Crossbite | | CF-CF Ratio | |
|---|---|---|---|
| At 1st Molar | Anywhere in Mouth | Model | CBCT |
| No | None | 1.12 | 1.15 |
| No | None | 1.11 | 1.14 |
| No | None | 1.13 | 1.17 |
| No | None | 1.13 | 1.13 |
| No | None | 1.15 | 1.14 |
| No | None | 1.13 | 1.12 |
| No | None | 1.09 | 1.15 |
| No | None | 1.19 | 1.14 |
| No | None | 1.11 | 1.13 |
| No | None | 1.15 | 1.16 |
| No | None | 1.12 | 1.11 |
| No | None | 1.12 | 1.14 |
| No | Bilateral | 1.14 | 1.16 |
| No | Bilateral | 1.1 | 1.13 |
| No | Bilateral | 1.06 | 1.09 |
| No | Unilateral | 1.07 | 1.09 |
| No | Unilateral | 1.15 | 1.16 |
| | | Proposed Healthy Cut-Off Ratio: 1.09 | |
| Yes | Bilateral | 0.98 | 1 |
| Yes | Bilateral | 0.95 | 0.94 |
| Yes | Bilateral | 0.88 | 0.92 |
| Yes | Bilateral | 1.02 | 1.03 |
| Yes | Bilateral | 1.03 | 1.05 |
| Yes | Bilateral | 1.03 | 1.07 |
| Yes | Bilateral | 1.03 | 1.05 |
| Yes | Unilateral | 1.05 | 1.04 |
| Yes | Unilateral | 0.99 | 0.98 |
| Yes | Unilateral | 1 | 1.02 |
| Yes | Unilateral | 1 | 0.99 |

| |
|---|
| Non-crossbite |
| Crossbite |
| Borderline |

**Table 16. Correlations between representative tooth and bone measurements among patients with CF-CF ratio equal to or greater than 1.10**

**Correlations**

| | | CBCT ratio maxilla furcation to mandible furcation | CBCT ratio maxilla buccal bone to mandible buccal bone | CBCT ratio maxilla CEJ to mandible CEJ |
|---|---|---|---|---|
| CBCT ratio maxilla furcation to mandible furcation | Pearson Correlation | 1 | .694** | .607* |
| | Sig. (2-tailed) | | .004 | .016 |
| | N | 15 | 15 | 15 |
| CBCT ratio maxilla buccal bone to mandible buccal bone | Pearson Correlation | .694** | 1 | .600* |
| | Sig. (2-tailed) | .004 | | .018 |
| | N | 15 | 15 | 15 |
| CBCT ratio maxilla CEJ to mandible CEJ | Pearson Correlation | .607* | .600* | 1 |
| | Sig. (2-tailed) | .016 | .018 | |
| | N | 15 | 15 | 15 |
| CBCT ratio maxilla lingual bone to mandible lingual bone | Pearson Correlation | .606* | .747** | .668** |
| | Sig. (2-tailed) | .017 | .001 | .006 |
| | N | 15 | 15 | 15 |
| CBCT ratio maxilla basal bone to mandible basal bone | Pearson Correlation | .699** | .609* | .470 |
| | Sig. (2-tailed) | .004 | .016 | .077 |
| | N | 15 | 15 | 15 |
| CBCT ratio maxilla CF to mandible CF | Pearson Correlation | -.666** | -.787** | -.456 |
| | Sig. (2-tailed) | .007 | .001 | .088 |
| | N | 15 | 15 | 15 |

| | | CBCT ratio maxilla lingual bone to mandible lingual bone | CBCT ratio maxilla basal bone to mandible basal bone | CBCT ratio maxilla CF to mandible CF |
|---|---|---|---|---|
| CBCT ratio maxilla furcation to mandible furcation | Pearson Correlation | .606* | .699** | -.666** |
| | Sig. (2-tailed) | .017 | .004 | .007 |
| | N | 15 | 15 | 15 |
| CBCT ratio maxilla buccal bone to mandible buccal bone | Pearson Correlation | .747** | .609* | -.787** |
| | Sig. (2-tailed) | .001 | .016 | .001 |
| | N | 15 | 15 | 15 |
| CBCT ratio maxilla CEJ to mandible CEJ | Pearson Correlation | .668** | .470 | -.456 |
| | Sig. (2-tailed) | .006 | .077 | .088 |
| | N | 15 | 15 | 15 |
| CBCT ratio maxilla lingual bone to mandible lingual bone | Pearson Correlation | 1 | .581* | -.549* |
| | Sig. (2-tailed) | | .023 | .034 |
| | N | 15 | 15 | 15 |
| CBCT ratio maxilla basal bone to mandible basal bone | Pearson Correlation | .581* | 1 | -.505 |
| | Sig. (2-tailed) | .023 | | .055 |
| | N | 15 | 15 | 15 |
| CBCT ratio maxilla CF to mandible CF | Pearson Correlation | -.549* | -.505 | 1 |
| | Sig. (2-tailed) | .034 | .055 | |
| | N | 15 | 15 | 15 |

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

**Table 17. Correlations between representative tooth and bone measurements among patients with CF-CF ratio less than 1.10**

**Correlations**

| | | CBCT ratio maxilla furcation to mandible furcation | CBCT ratio maxilla buccal bone to mandible buccal bone | CBCT ratio maxilla CEJ to mandible CEJ |
|---|---|---|---|---|
| CBCT ratio maxilla furcation to mandible furcation | Pearson Correlation | 1 | .762* | .569 |
| | Sig. (2-tailed) | | .010 | .086 |
| | N | 10 | 10 | 10 |
| CBCT ratio maxilla buccal bone to mandible buccal bone | Pearson Correlation | .762* | 1 | .579 |
| | Sig. (2-tailed) | .010 | | .079 |
| | N | 10 | 10 | 10 |
| CBCT ratio maxilla CEJ to mandible CEJ | Pearson Correlation | .569 | .579 | 1 |
| | Sig. (2-tailed) | .086 | .079 | |
| | N | 10 | 10 | 10 |
| CBCT ratio maxilla lingual bone to mandible lingual bone | Pearson Correlation | .036 | .161 | .361 |
| | Sig. (2-tailed) | .922 | .658 | .306 |
| | N | 10 | 10 | 10 |
| CBCT ratio maxilla basal bone to mandible basal bone | Pearson Correlation | .695* | .681* | .666* |
| | Sig. (2-tailed) | .026 | .030 | .035 |
| | N | 10 | 10 | 10 |
| CBCT ratio maxilla CF to mandible CF | Pearson Correlation | -.844** | -.751* | -.393 |
| | Sig. (2-tailed) | .002 | .012 | .262 |
| | N | 10 | 10 | 10 |

| | | CBCT ratio maxilla lingual bone to mandible lingual bone | CBCT ratio maxilla basal bone to mandible basal bone | CBCT ratio maxilla CF to mandible CF |
|---|---|---|---|---|
| CBCT ratio maxilla furcation to mandible furcation | Pearson Correlation | .036 | .695* | -.844** |
| | Sig. (2-tailed) | .922 | .026 | .002 |
| | N | 10 | 10 | 10 |
| CBCT ratio maxilla buccal bone to mandible buccal bone | Pearson Correlation | .161 | .681* | -.751* |
| | Sig. (2-tailed) | .658 | .030 | .012 |
| | N | 10 | 10 | 10 |
| CBCT ratio maxilla CEJ to mandible CEJ | Pearson Correlation | .361 | .666* | -.393 |
| | Sig. (2-tailed) | .306 | .035 | .262 |
| | N | 10 | 10 | 10 |
| CBCT ratio maxilla lingual bone to mandible lingual bone | Pearson Correlation | 1 | .220 | -.171 |
| | Sig. (2-tailed) | | .541 | .637 |
| | N | 10 | 10 | 10 |
| CBCT ratio maxilla basal bone to mandible basal bone | Pearson Correlation | .220 | 1 | -.388 |
| | Sig. (2-tailed) | .541 | | .267 |
| | N | 10 | 10 | 10 |
| CBCT ratio maxilla CF to mandible CF | Pearson Correlation | -.171 | -.388 | 1 |
| | Sig. (2-tailed) | .637 | .267 | |
| | N | 10 | 10 | 10 |

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

# DISCUSSION

Advances in digital imaging have made it possible to obtain 3D representations of craniofacial structures utilizing CBCT scans. These scans allow the orthodontist to make accurate diagnoses in all three planes of space and overcome the inaccuracies of projection, magnification and landmark identification seen with 2D cephalograms (Major et al., 1994; Major et al., 1996; Ghafari et al., 1995; Huertas and Ghafari, 2001). Accordingly, routine CBCT scans of orthodontic patients may allow for better diagnosis and treatment planning. However, due to the risk of exposing patients to radiation, it is imperative to ensure that these scans will provide necessary information which would otherwise be unobtainable through conventional diagnostic methods.

Hence, the purpose of this study was to examine the accuracy, reliability, and necessity of CBCT in assessing the transverse dimension. Comparisons were made between patients that exhibited clinical crossbite at the first molar level to those without crossbite at the first molar level. In order to test the appropriateness of the ABO's use of dental casts to measure the skeletal transverse dimension, comparisons between CBCT and model measurements were made and an assessment of the ability of CBCT to provide additional diagnostic information on skeletal transverse dimension was performed.

We found that measurements at the CF and MB were not significantly different between the CBCT and models. However, measurements made at the lingual CEJ were significantly different between the CBCT and models. This difference can be explained by how the CEJ was measured on each source. CBCT scans allow for visualization of the true CEJ, while the soft tissue usually prevents such visualization on the models.

Therefore, model measurements of CEJ are only able to be made at the free gingival margin as opposed to the true anatomical location by its definition.

Ratio comparisons of tooth and bone measurements for the maxilla and mandible on both model and CBCT showed that non-crossbite means were larger for all ratios. This result is expected as maxillary measurements should be larger than mandibular measurements if no crossbite is present. Crossbite standard deviations were generally larger than non-crossbite standard deviations. Again, this result is expected as there can be a wide range of deviations from normal.

In exploring the relationships among the different measurements from the CBCT, we found that the CF best represented the other tooth measurements ($p < 0.01$). Accordingly, the data suggest that transverse tooth measurements on model and CBCT should be made at the CF, and that these measurements should be nearly identical. However, all bone measurements gave different information, and none of them can be ignored in performing a transverse analysis on CBCT.

Our study was a continuation of the work of Miner et al. in developing a CBCT transverse analysis. While their study only used patients with normal Class I occlusion, this study included patients with various sagittal first molar relationships. Due to the differences in these relationships, the method for orienting the images was altered to accurately view maxillary and mandibular first molar regions on separate slices.

Miner et al. were not able to totally eliminate the effect of tooth position on skeletal widths while using their particular landmarks. A goal of this study was, therefore, to find an accurate representation of basal bone. A systematic review by Van der Weijden et al. examined alveolar bone dimensional changes of post-extraction sockets in humans. They found that the mean clinical mid-buccal height loss was 1.67 mm., the mean crestal height change as assessed on the radiographs was 1.53 mm and the socket fill in height as measured relative to the original socket floor was on an average 2.57 mm (Van der Weijden et al., 2009). We wanted our measurement of basal bone to be apical to these levels to minimize the effect of tooth position. As such, we felt that measuring basal bone width at the level of the first molar apices was appropriate.

Miner et al. developed linear and angular normative values for CBCT transverse analysis. These values can be seen in **Table 18** (Miner et al., 2012). Comparing our measurements to theirs would have been inaccurate due to differences in orientation. Additionally, the authors of this paper felt it inappropriate to judge every patient against such normative values. Differences in patient genetics could result in higher or lower values for maxillary and mandibular widths, but not necessarily result in posterior crossbite. A ratio between maxilla and mandible seemed more appropriate for diagnostic purposes. Therefore, we sought instead to determine a normative ratio for non-crossbite patients between maxillary and mandibular measurements made at the CF. Our sample showed that a CF-CF ratio of equal to or greater than 1.10 was generally present in non-crossbite patients, while all crossbite patients had a CF-CF ratio less than 1.10. There were two non-crossbite patients that had a CF-CF ratio less than 1.10 when measured on the model. While these two patients did not have a crossbite at the first molar level, they had posterior crossbites (1 bilateral and 1 unilateral) at other tooth levels. These crossbites may have contributed to a narrower maxillary CF measurement at the first molar level, which in turn, would have resulted in a CF-CF ratio less than 1.10. Patients with any posterior crossbite at any tooth level should ideally be excluded from the non-crossbite group in future studies.

**Table 18. CBCT transverse analysis linear and angular normative values as presented by Miner et al.**

| *Measurement* | *Mean ± SD* | *Range* |
|---|---|---|
| Molar axial angle, maxillary right (°) | 97.77 ± 2.7 | 84.6-115.0 |
| Molar axial angle, maxillary left (°) | 98.29 ± 2.56 | 87.6-114.0 |
| Molar axial angle, mandibular right (°) | 104.22 ± 2.67 | 89.6-124.8 |
| Molar axial angle, mandibular left (°) | 103.85 ± 2.47 | 87.7-118.0 |
| Maxillary palatal S′ width (mm) | 27.73 ± 2.08 | 19.3-35.0 |
| Mandibular lingual S′ width (mm) | 28.95 ± 2.79 | 20.9-47.6 |
| Maxillomandibular S′ width differential (mm) | −1.22 ± 2.91 | −24.6-11.2 |

The proposed normative CF-CF ratio of 1.10 was used when further exploring correlations between measurements at CF and bone measurements. Non-crossbite patients with a CF-CF ratio equal to or greater than 1.10 showed generally strong relationships between CF and all bone measurements. This suggests that the CBCT did not provide much additional diagnostic information about the bone when compared to the model and that bone width could be reasonably predicted from the tooth width. This may, however, not be true for assessing basal bone, as there was only a borderline relationship noted. This uncertainty would require a larger sample size to explore. For patients with a CF-CF ratio less than 1.10, only a relationship with CF and buccal bone at furcation level was found. This suggests that buccal alveolar bone width is highly affected by tooth position. However, no relationship was found between CF and lingual/palatal alveolar bone at the furcation level nor between CF and basal bone.

Subsequently, this suggests that CBCT does provide additional diagnostic information about the bone for patients with a CF-CF ratio less than 1.10 and that bone width cannot be predicted based on the CF-CF ratio alone for these patients.

Like all others, this investigation had several limitations. Weaknesses exist due to the retrospective nature of the study. A small sample size limits the validity of our results and a larger sample is needed for confirmation. We limited our CBCT measurements to one slice for the maxilla and mandible. Because of how the slices were oriented and where each slice was taken, landmark identification may not have always been consistent, especially for furcation and root apices. While the ICC suggests that these landmarks were measured consistently, allowing for a range of slices antero-posteriorly may have allowed for better identification of such landmarks, and therefore, more accurate measurements.

# SUMMARY AND CONCLUSION

Within the limitations of this study, the following conclusions are summarized:

1. With reference to landmark CF, the CBCT image is identically consistent with the dental model.
2. When measuring the transverse dimension (dental and/or skeletal), measurements across CF should be used, which gives the best representation of all other measurements.
3. A ratio of maxilla over mandible CF measurements appears to be equal to or greater than 1.10 for non-crossbite patients. For patients without clinical crossbite and CF-CF ratio equal to or greater than 1.10, no further diagnostic information about the underlying bone is obtained from taking a CBCT scan. However, diagnosis of patients with clinical crossbite and CF-CF ratio less than 1.10 may benefit from having a CBCT scan taken.
4. Our results likely support the ABO's use of dental models in assessing the transverse dimension ONLY in patients without crossbite.

Future research should include a larger sample size to validate the results of this study, as well as to compare the CF-CF ratio against known designations for narrow, normal, or wide bone width of the maxilla.

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